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SPACE SHUTTLE VISUAL SIMULATION SYSTEM DESIGN STUDY

DESIGN RECOMMENDATION REPORT

MCDONNELL DOUGLAS
CORPORATION

COPY NO. ___

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20 JULY 1973 REPORT MSC 06741

Prepared By

McDonnell Douglas Electronics Company

Submitted in accordance with the Data Requirements List, line item number 6 and data description item number 6, contained in Contract Number NAS 9-12651.

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1.0 INTRODUCTION

The purpose of this report is to provide a recommendation and a specification for the visual simulation system design for the Shuttle Mission Simulator. A recommended visual system is described which most nearly meets the visual design requirements for the Shuttle Mission Simulator. These requirements are stated in the Design Requirements Specification and are presented as Appendix A to this report. This document is the end product of the design study. The principle sources for the content are the contemporary (Report MSC 06743) and analytical (Report MSC 06742) study phases.

Also contained in this document is a cost analysis of the recommended system covering design, development, manufacturing, and installation. Four alternate systems are presented and discussed.

2.0 BASELINE VISUAL REQUIREMENTS

A Design Requirements Document (MSC 06744) was prepared during the initial study phases which defined performance and design goals for the Shuttle Visual System. Requirements for viewing geometry, scene elements, scene dynamics and perceptibility were formulated, initially from all of the available Phase B proposal data, and later revised to reflect the best understanding of the Rockwell vehicle configuration. Later changes in the vehicle viewing geometry, including the addition of a viewing cupola for payload handling operations, were factored into the Analytical Study. The final version of the requirements document is included as Appendix A to this report. The dynamics section is unchanged from the Revision B version of the August 1972 submittal, since a slightly higher than actual range of vehicle dynamics was assumed as a specification safety margin. Due to a succession of changes in the overall vehicle configuration and weight, the SRM and fuel tanks are now visible in the forward field, and have been deleted as a simulation scene element requirement.

3.0 RECOMMENDED BASELINE SYSTEM

The system presented in this and subsequent report sections is recommended as most nearly meeting the overall design requirements. The recommendation is made on the basis of the anticipated performance of the best available state of the art in components and subsystems. A hybrid approach which employs both television-model and computed image techniques has been selected.

Four alternate systems of reduced size and complexity are presented. In three of the systems the forward and aft fields of view are narrowed, and the complexity of image generation equipment reduced. All of the systems provide visual cue simulation in all mission phases from ascent, on-orbit, re-entry, ferry, landing, and take-off.

3.1 BASELINE SYSTEM COMPONENTS: SUMMARY SELECTION RATIONALE

The rationale for the selection of the image source, image sensing displays in the baseline system is shown in summary form in figures 3.1 and 3.2 which show in qualitative form the principle conclusions drawn from the analytical portions of the study, and leads directly to the selection of the anticipated best match between scene element and simulation technique. Other criteria which influenced simulation technique selection were as follows:

a. The minimization of the number of image source types in the overall system.

b. Minimum displays system complexity and weight.

Subsystem selection was also heavily influenced by the intent to preserve scene brightness and detail resolution in all displayed images.

3.2 OVERVIEW OF RECOMMENDED SYSTEM

Figure 3.3 shows the principle components of the recommended system, and figure 3.4 is a functional block diagram.

Five articulated optical probes and camera pre-amplifiers sense the high altitude, low altitude, orbital earth, and cloud/sky/terminator unit. Video signals for

RECOMMENDED BASELINE SYSTEM: SUMMARY RATIONALE

SCENE ELEMENT	APPLICABLE TECHNIQUES	ADVANTAGES	DISADVANTAGES	RECOMMENDATION
ORBITAL EARTH	TV/MODEL EARTH SPHERE	• RELIABLE, WELL ESTABLISHED TECHNOLOGY • LARGE DATA BASE • HIGH RESOLUTION DETAIL POSSIBLE • CORRECT PERSPECTIVE EFFECTS • COMPACT	• TWO COMPLETE SYSTEMS REQUIRED • SEPARATE TERMINATOR AND CLOUD COVER IMAGE SOURCE REQUIRED	TV/MODEL EARTH SPHERE
	FSS/TRANSPARENCY	• IMAGE SOURCE DATA EASILY MODIFIED • CLOUD COVER AND TERRAIN AVAILABLE SIMULTANEOUSLY • SOURCE DATA EASILY PREPARED	• MULTICHANNEL SYSTEMS REQUIRED • PERSPECTIVE REGENERATION PROBLEMS • RESOLUTION LIMITED BY CRT BEAM SCANNING APERTURE	
HIGH ALTITUDE EARTH	TV/MODEL	– AS FOR ORBITAL EARTH –	• ACCURATE CO-ORDINATION OF TRANSITION POINT REQUIRED	TV/MODEL
	FSS/TRANSPARENCY	– AS FOR ORBITAL EARTH –		
LOW ALTITUDE EARTH	TV/MODEL	– AS FOR ORBITAL EARTH –	• LARGE TERRAIN MAP REQUIRED TO ACCOMPLISH FULL FINAL APPROACH MANEUVER, AND POSSIBLE ABORT SITUATIONS • 3000:1 SCALE AND 0.08" POINT OF CLOSEST APPROACH	TV/MODEL
	CGI	• DATA BASE EASILY MODIFIED AND UPDATED • SEVERAL FIELDS FROM SINGLE LOOK POINT • COLOR PROCESSING SIMPLICITY • RAPIDLY ADVANCING TECHNOLOGY	• EXTREMELY LARGE DATA BASE REQUIRED TO OFFSET LACK OF REALISM • REALISTIC TERRAIN TEXTURING DIFFICULT, RECTILINEAR IMAGERY	
STAR FIELD	STAR SPHERE	• POINT SOURCE IMAGERY • ACCURATE STAR MAGNITUDE SIMULATION	• OPTICAL MULTIPLEXING REQUIRED • WIDE (>120°) FIELD DIFFICULT TO MECHANIZE • TWO SPHERES REQUIRED, ONE PER EYEPOINT • OCCULTATION PROBLEMS	CGI
	CGI	• OPERATIONAL SIMPLICITY • OCCULTATION FEASIBLE	• MIN STAR SUBTENSE APPROX. 6 ARC-MIN • STAR SIZE GROWTH WITH INCREASING INTENSITY	
RENDEZVOUS AND DOCKING TARGETS	TV/MODEL	• RELIABLE WELL ESTABLISHED TECHNOLOGY • HIGH DEGREE OF REALISM POSSIBLE	• DIFFERENT MODEL SCALES REQUIRED FOR FORE AND AFT FIELDS. • SCENE CONTINUITY FROM FORWARD TO AFT DIFFICULT TO OBTAIN.	CGI
	CGI	• IMAGE DATA EASILY MODIFIABLE • SHARED DATA BASE FOR FORWARD AND AFT FIELDS. • GOOD REALISM WITH SCENE FILTERING AND SMOOTHING	• LESS REALISTIC THAN SCALE MODEL APPROACH • MULTILEVEL DATA BASE PROCESSING REQUIRED TO SIMULATE VERY CLOSE APPROACH	
CLOUD COVER AND TERMINATOR	TV/TRANSPARENCY	• GOOD REALISM, AND VARIABLE CLOUD COVER POSSIBLE. • HORIZON HAZE FOR TERRAIN SCENES. • TERMINATOR SEPARATED FROM ORBITAL EARTH MODEL REDUCES MODEL EARTH COMPLEXITY.	• LARGE HEMISPHERICAL SCREEN REQUIRED TO REDUCE HORIZON CURVATURE EFFECTS AT LOW ALTITUDES.	TV/TRANSPARENCY
	TV MODEL	• HIGH DEGREE OF REALISM POSSIBLE.	• VARIABLE CLOUD FORMATIONS DIFFICULT TO MECHANIZE.	
AFT ORBITER BODY AND RMS	TV MODEL	• NO SIGNIFICANT ADVANTAGES OVER CGI DUE TO SIZE AND COMPLEXITY OF SYSTEM.	• 4:1 SCALE MODEL MINIMUM. • COMPLEX TRANSPORTER MECHANISMS REQUIRED FOR ARM MOTION SIMULATION. • SET OF PAYLOAD MODELS REQUIRED OF DIFFERENT SCALE TO FORWARD FIELD.	CGI
	CGI	– AS FOR RENDEZVOUS AND DOCKING TARGETS –	– AS FOR RENDEZVOUS AND DOCKING TARGETS –	

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FIGURE 3.1 RECOMMENDED BASELINE SYSTEM

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SYSTEM ELEMENT	APPLICABLE TECHNIQUE	ADVANTAGES	DISADVANTAGES	RECOMMENDATION
FORWARD AND AFT FIELD DISPLAY OPTICS	REFRACTIVE OPTICS	• LOW LIGHT LOSS (0.8 TRANSMISSION FACTORS POSSIBLE)	• EDGE REGISTRATION DIFFICULT • MULTI ELEMENT DESIGNS REQUIRED • RESIDUAL ABERRATIONS DIFFICULT TO REMOVE	
	IN-LINE REFLECTIVE	• NO CHROMATIC ABERRATION • EASILY EDGE REGISTERED • COMPACT ASSEMBLY	• SIGNIFICANT LIGHT LOSS (TRANSMISSION LESS THAN .03)	
	OFFSET REFLECTIVE (NON PUPIL FORMING)	• NO CHROMATIC ABERRATION • EASILY EDGE REGISTERED • FAIRLY COMPACT ASSEMBLY	• LIMITED VERTICAL FIELD • SPHERICAL INPUT IMAGE SURFACE REQUIRED	OFFSET REFLECTIVE (NON PUPIL FORMING)
	OFFSET REFLECTIVE (PUPIL FORMING)	• NO CHROMATIC ABERRATION • VERTICAL FIELDS GREATER THAN 60° POSSIBLE • EASILY EDGE REGISTERED	• BULKY ASSEMBLY • PUPIL MAY RESTRICT HEAD MOTION	CANDIDATE FOR AFT FIELD DISPLAYS IN ALTERNATE "A" SYSTEM
DISPLAY DEVICE	HIGH INTENSITY PROJECTION KINESCOPES (MATCHED TRIOS)	• HIGH LUMINANCE • WELL ESTABLISHED TECHNOLOGY	• POOR RESOLUTION AND CONTRAST • LONG THROW PROJECTION OPTICS REQUIRED • PACKAGING COMPLICATIONS (18 TUBES REQUIRED FOR FORWARD FIELD)	
	SIMULTANEOUS COLOR LIGHT VALVE	• NO REGISTRATION PROBLEMS • HIGH LIGHT OUTPUT AND HIGH CONTRAST	• 625 TV LINE RESOLUTION LIMITATION	
	HIGH RESOLUTION SHADOW MASK CRT	• 900 TV LINE CENTER FIELD RESOLUTION • LIGHT WEIGHT, COMPACT PACKAGE	• 75 FOOT LAMBERTS MAX LIGHT OUTPUT • MOIRÉ EFFECTS	HIGH RESOLUTION SHADOW MASK CRT

FIGURE 3.2 RECOMMENDED BASELINE SYSTEM: DISPLAYS

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT	IGE
Orbital Earth	- Two 6' diameter spheres landmark areas to .001" detail
High Altitude	- 800,000:1 scale, 8' × 8' area, coverage 1000 × 1000 nmi
ORBITAL AND HIGH ALTITUDE	
Clouds, Ascent Sky, Terminator	- 3 transparency projectors • ascent sky • orbital cloud cover • High altitude clouds
LOW ALTITUDE	- 40' × 40' map model, 3000:1 scale
Rendezvous, Payload, Docking Targets, Orbiter Body, Star Field, RMS TV Displays	- 4 Channel CGI system, 5 lookpoints. 3 assigned to observer eyepoints, 2 assigned to payload station TV displays. CGI generates keying signals, and RMS adapter/payload contact events.

IMAGE SENSING AND PROCESSING

Sensing:

5 - 3 channel optical probes, total field of view 140° × 37° per unit. 3 position azimuth detent to permit for assignment to commander or pilot. 3 image isocons per probe. Color by spatial frequency encoding.

Processing:

50 MHz video channels. 150 MHz total bandwidth per probe total field chrominance data extracted by electronic filtering.

All scene elements mixed and inset electronically. CGI keying accepted by video processing unit. Rendezvous CGI targets switched into forward active displays. Orbital earth scene appears in aft field.

DISPLAYS

Display Device

25" shadow mask high definition CRT, resonant 1350 line deflection system, 4:3 aspect ratio. 900 TV line resolution in center field.

Forward Displays Package

Six reflective optics unit. Edge registered, three per forward eyepoint. 4 display units active at any one time, with line-of-sight either forward, biased inboard, or outboard.

Aft Displays Package

3 edge registered units vertically stacked. Mechanical assembly to rotate displays stack from overhead view seat position to nominal seat position. Line of sight tracked by CGI equipment to modify channel content in accordance with line of sight direction.

Aft displays also receive earth scene from orbital earth model.

2 TV monitors for wrist/payload close-in operations, operated from CGI equipment, operated on an either/or basis.

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FIGURE 3.3 RECOMMENDED SYSTEM COMPONENTS

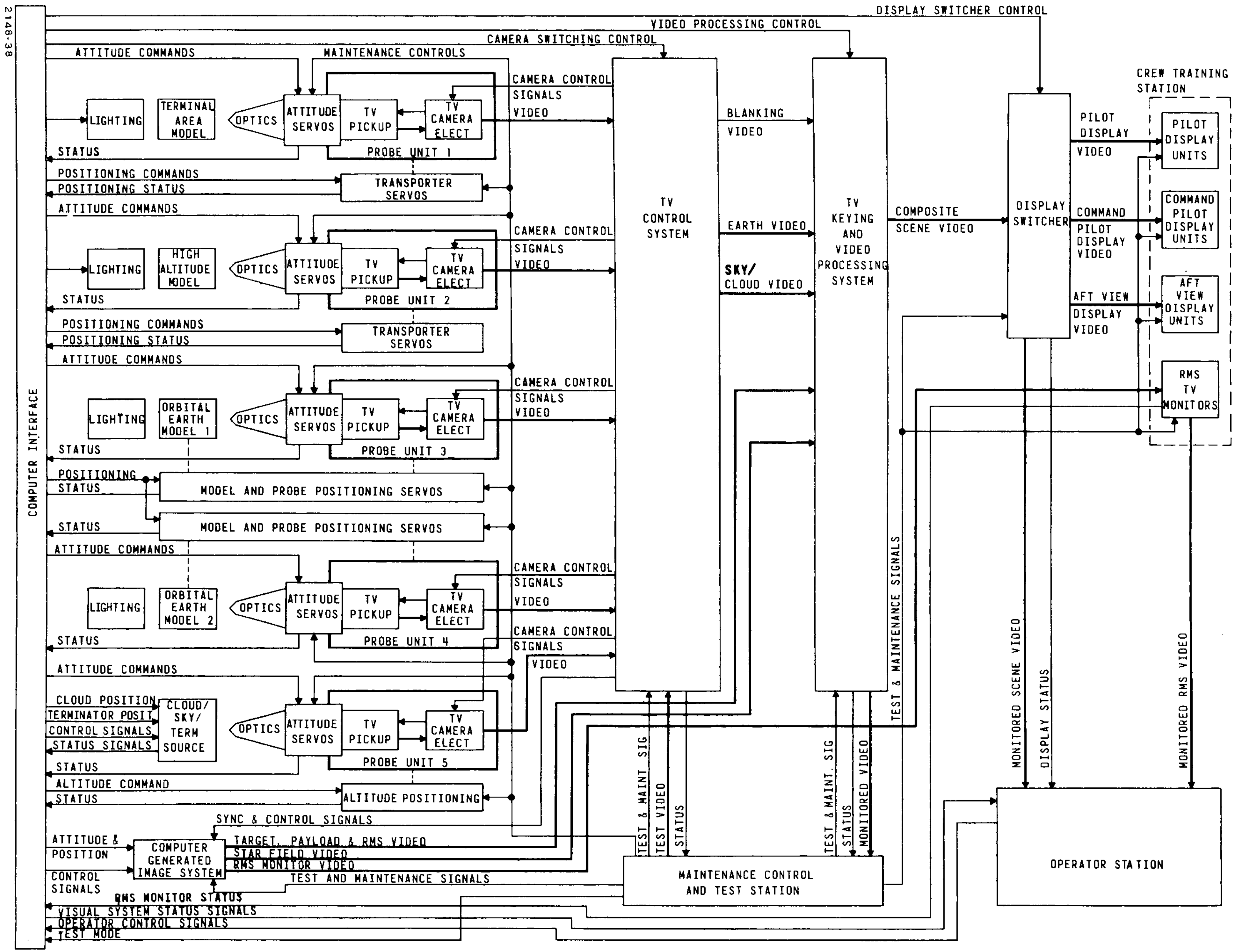


FIGURE 3.4 RECOMMENDED SYSTEM BLOCK DIAGRAM

rendezvous targets, payload, aft Orbiter, Remote Manipulator System, star field and RMS monitor are provided by computer generated image equipment. Command signals for probe attitude positioning, camera transports and model drives are supplied by the Mission Simulator computer interface.

Position and attitude data for the CGI system eyepoint, RMS arm element, and rendezvous target dynamics computations are also provided by the Mission Simulator computer complex.

Status signals for the servo drive subsystem are fed back to the computer interface for improper tracking indications, limit warnings and other equipment malfunctions.

Computer control signals to lighting units for terminal area and high altitude models are required for day/night control. Control signals supplied to the cloud/sky/terminator projection system are needed for activating the proper cloud cassette or artificial horizon projector and control of fog/haze density and ceiling. Control signals to the CGI system provide selection of eyepoints to be activated, and various other control parameters.

Signals for controlling TV camera portions of the probe units are supplied by the TV Control System. Signals such as vertical and horizontal sweeps, blanking, focus control, and beam controls are contained in these lines.

The sweeps and blanking signals are controlled by a master synchronization section of the TV Control System. These synchronizing signals are also needed by the CGI system so that the generated video is compatible with the other video signals. Under external computer control, the video switcher portion of the TV Control System selects the appropriate earth model video signals required for the particular phase of the Shuttle mission. The basic scene element video signals of earth and cloud/sky are then supplied to the TV Keying and Video Processing System together with a video blanking signal. Test video from the Maintenance Control and Test Station can also be selected and supplied to the output for test and/or alignment.

The TV Keying and Video Processing System accepts the four basic video signals of earth video, cloud/sky video, target/payload/RMS video and star field video, and performs the appropriate processing to obtain composite scene video with the appropriate image insetting and special effects for realistic simulation of the out-the-window scenes. Certain special effects require computer inputs for gain control.

The Display Switcher under computer control routes the composite scene video to the appropriate display units of the crew training station and supplies a video signal together with status indication to the Operator Station. The operator may select one of the three segments of the field for monitoring purposes.

In addition to the forward and aft visual displays, two CCTV monitors are provided at the payload handling station. These units monitor close-in latching and securing operations between each of the RMS wrist adapters and payload.

Camera selection is made at the payload handling station and a RMS Monitor status signal routed through the computer interface, and back to the CGI system, determines the eyepoint position to be simulated by the CGI system in generating the RMS monitor video. The RMS monitor video selected is also routed to the Operator Station for monitoring.

For the purposes of testing, alignment, and maintenance, a Maintenance Control and Test Station is recommended. This unit provides manual slew control for the various servos, test initiation signals for CGI equipment, Test Video patterns for system alignment, manual select signals for camera switching and display switching, and other maintenance and test mode signals for the components of the visual system. Status signals received back from the Camera Control Unit and TV keying system provide troubleshooting and alignment aids. Also, composite scene video from the TV keying system is supplied to the Maintenance Control Station for selective monitoring during test and maintenance modes. A test mode discrete signal is fed to the computer to indicate that the visual system is off line.

A portion of the Operator Station is utilized for monitoring and control of the visual system. Monitors for composite scene video and RMS video are provided and various status indicators are included to indicate which portions of the visual system are on line. Control signals such as visibility range and ceiling, cloud density and status check are sent to the computer interface from the Operator Station for operator control and operability checks.

3.3 DETAILED SYSTEM DESCRIPTION

3.3.1 Orbital Earth Scene

The Orbital Earth Scene is provided by two identical earth models. Two models are required (see Analytical Report Section 4.3.1.1) due to the need for continuous earth surface coverage during polar and near-polar inclinations. One model is driven with 360° continuous freedom about a polar axis, the other with 360° freedom about an equatorial axis. Other rotational freedoms required for model-to-model scene transition are illustrated in figure 3.5. Model diameter is primarily determined by detail rendering and is expected to be not less than 6 feet, and may be increased to 8 feet maximum in the interests of meeting resolution element size requirements, provided dimensional tolerances scaled proportionally from the specification data can be met.

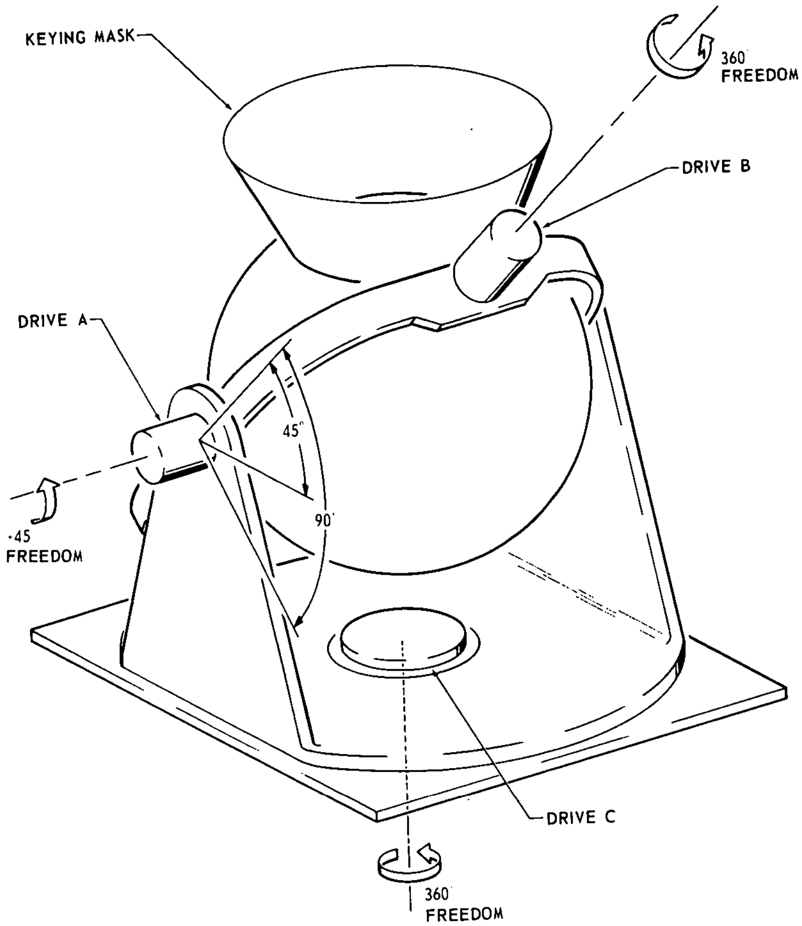
Each sphere is of identical construction and consists of inner and outer elements. The outer element is a pair of hemispherical shells of epoxy fiberglass or acrylic. The inner element is bonded to a hollow steel shaft and provides the attachment point and supports for the hemispherical shells.

The models are driven by dc servo motors and speed reduction devices. Either worm or recirculating ball screw reduction mechanisms may be employed. A typical servo drive channel is shown in figure 3.5.

Sphere decoration is by conventional techniques, but landmark areas are derived ERTS imagery photographed directly onto the model surface. ERTS RBV (Return Beam Vidicon) imagery corrected for camera and vidicon geometric errors is used for this purpose.

Each Sphere is fitted with a conical screen positioned over the model so as to expose a surface area of approximately 5.3 square feet (60° geocentric angle). The screen serves as a horizon mask and also occults mechanical components of the model support and drive mechanisms.

Model illumination is from a diffuse source of 7,000 lumens output which provides 1,500-foot candles surface illuminance. No special problems in heat removal are foreseen since incident infrared irradiation is not likely to exceed 300 watts. Local shadows from the probe and probe altitude transport mechanism may be reduced if necessary by small auxiliary light sources carried by the transport mechanism.



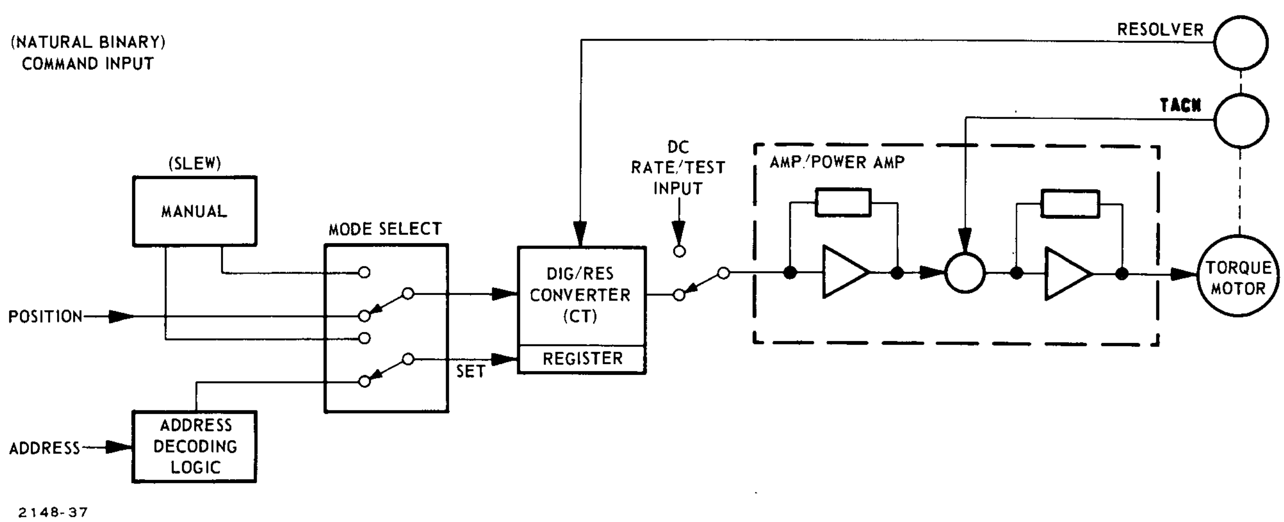


FIGURE 3.5 EARTH SPHERE ANGULAR FREEDOMS AND DRIVE MECHANISMS

Each earth sphere is sensed by a 3-channel optical probe. The probes are provided with an electro-mechanical detent for the purposes of changing the alignment of the center of the total field of view to any of the following three positions:

Position 1: Probe optical axis aligned along the nominal center line of sight.

Position 2: Probe axis displaced 45° outboard from Position 1.

Position 3: Probe axis displaced 45° inboard from Position 1.

In position 1, identical center fields are presented to the commander and pilot. The left and right channels are assigned to the left and right forward field vehicle quarter windows.

In position 2, identical center fields are presented, and the left quarter and side windows are activated.

Probe position 3 provides center field, and right quarter and side window display.

This mode of operation in essence permits probe assignment to either vehicle commander or pilot. Forward field coverage is therefore 225° in three moveable fields of 135°. This approach is also used in the high and low altitude models. The probe direction assignment is also signaled to the CGI equipment for the purposes of changing the CGI channel field-of-view computations.

3.3.2 High Altitude Model

The high altitude model consists of a scaled representation of approximately 1,000 x 1,000 nm land area. A conventional camera transport mechanism provides the required translational freedoms. The model is square, 8 feet by 8 feet and scaled at 734,000:1. Standard decoration techniques using cartographic and aerial reconnaissance data sources are employed.

It is conceivable that a high-quality high-altitude earth model could be constructed by using ERTS RBV (Return Beam Vidicon) imagery exclusively. The high altitude model would take the form of a large photomosaic color transparency bonded to a rear illuminated glass plate. Investigation of ERTS data formats indicate however, that the basic 115 x 115 statute mile photographic frames would require additional processing in order that a flat earth mosaic could be assembled. Individual frames, after first-level processing to remove video and optical errors, contain a small amount of image barrel distortion resulting from earth curvature away from the nadir point, located at the center of the frame. This effect would be removed by re-processing the frames with a lens having the correct degree of pincushion distortion. A large number of overlapping image-corrected frames would be required and possibly some hand-retouching would be required to minimize the effects by frame-to-frame cloud cover discontinuities.

Since the ERTS program may not be sufficiently advanced to provide all of the imagery required by the high altitude model, it is recommended that conventional modeling techniques be used, supplemented by ERTS data for specific areas of interest.

Model illumination requirements are met by fluorescent diffuse lighting of 85,300 lumens total.

3.3.3 Low Altitude Model

The vertically-mounted low altitude model provides landing and takeoff scenes under variable simulated weather conditions and visibility. Apart from physical size, which dictates a vertical reach of approximately 40 feet in the camera transport mechanism, a conventional approach to a 3,000:1 scale model construction and illumination is recommended. Model detail rendering conforms to the perceptibility criteria defined in the final analytical report section 2.0. Emphasis is therefore placed on realism in the runway and immediate landing area environment, all weather markings, and ILS visual aids. The model resolution element size in the immediate runway touchdown area is .002". Thus assuming that a landing flare is performed at an eyepoint altitude of 105 feet, with a maximum downlook angle of 20°, demarkation between a centerline stripe and runway texture subtending 6 arc-minutes is provided by the model, at minimum line-of-sight range of approximately 700 feet.

The model is illuminated with a total of 2.4×10^{6} lumens from banked fluorescent lamps. A total of 240 60-inch tubes are used with a total power consumption of 33 KW. The camera transport mechanism is supported at the gantry head by a rail to minimize sway and vibration, and to maintain orthogonality tolerances.

3.3.4 Orbital and High Altitude Cloud Scenes

Variable cloud cover for the orbital and high altitude earth scenes, special effects horizons for the high altitude and low altitude scenes, and the earth terminator are generated by a single unit. This unit employs a group of three film strip projectors which image high altitude, orbital and ascent sky/cloud scenes internally on a hemispherical rear projection screen with a 6-feet radius of curvature. An internally-decorated keying mask is arranged above the model in a similar manner to the earth model.

The cloud scene projectors operate individually and sequentially to produce the required sequence of cloud effects. No beamsplitters are employed. In order to illuminate the inside surface of the rear projection screen to the required level of 1,500-foot candles, each projector outputs an open-gate illumination of 28,000 lumens. The film format, projection lens and projection conjugates are chosen to limit the film strip visible light irradiance to 1,000 lumens per square centimeter or less, and two-stage dichroic filters are used in the projection lamp housing to limit residual infrared film radiance to below 2 watts per square centimeter.

The terminator mask is driven in azimuth and elevation, and rotates in close proximity with the internal projection screen, appropriately occulting the cloud cover imagery.

The scale of the unit is twice that of the earth model, and provides cloud scenes to an effective scaled altitude of approximately 75,000 feet, with a small amount of horizon curvature due to the projection screen curvature.

3.3.5 Aft Orbiter and RMS Scenes

The aft orbiter body, RMS (Remote Manipulator System), star field, payload, rendezvous and docking targets scenes are provided by computer generation equipment. The CGI equipment display format is identical to the forward field CCTV format, thus permitting the insertion of star field, rendezvous targets and docking targets at the correct angular location and size.

Three channels of computed image data are generated for forward and aft external displays. A fourth channel is used for either one of two RMS television monitors at the payload handling station, depending on which arm is active.

During on-orbit mission phases at those times that the payload station is inactive, the three CGI channels are assigned to the forward field and supplement the active displays with star field and rendezvous target data. The origin of the eyepoint calculations is centered between the commander and pilot design eyepoints. The three CGI channels also track the probe azimuth assignment directions, positions 1, 2 and 3.

At those times during which the payload station is manned, the CGI equipment supplies three channels of data to the aft displays. Two reference eyepoints, A and B, are used. Position B is the nominal eyepoint position for aft payload and operations. Position A permits overhead viewing with cargo handling seat retracted and back-tilted. Computations are performed using positions A or B, depending on seat position. Two television displays are activated on an either/or basis by the CGI equipment, for the purposes of simulating the view from real world cameras at the RMS wrist mechanism.

The CGI equipment operates from a data base of 2,250 real time edges, edge-smoothing and shading is employed. One-thousand edges are assigned to the simulation of the aft orbiter view and RMS arms. A software catalog of 12 rendezvous and payload models is available, any one of which is selected for mission operations. Data base granularity is 1/64 foot for all scene elements. A 1,000 light point processing capability is included in data base for the representation of the celestial sphere in either the forward or aft fields of view.

3.3.6 Image Sensing and Processing

A three-channel 140° articulated optical probe is used to sense all model and transparency image generation equipment. In order to meet resolution requirements in the Orbital Earth, High and Low Altitude and Cloud models, the probe must focus a near point line of sight distance of 10 mm, depressed 17° from the optical axis. The probe resolving capability is 5 arc-minutes or better over a semi-field angle of 50°, and 7 arc-minutes or better over the full semi-field angle of 70°. (These figures appear to be feasible in an existing design, with the exception that the extreme 2-1/2^{o} at the edges of the field may be more degraded.) Probe point of closest approach is 0.2" in the case of all image generation equipment other than the Low Altitude model. In the latter instance an approach distance of 0.106" or 2.85 mm is required. This is a technical risk area, and is discussed in Section 3.3.13.

Three Image Isocon pickup tubes per probe are used to generate wide band video signals. A developmental model isocon is recommended that is capable of 2,000 TV lines resolution at a faceplate highlight illuminance of .008-foot candles (an existing production model isocon is capable of 1,100 TV lines resolution at an illuminance of 2×10^{-3} foot candles. In determining model illumination requirements, a model surface illuminance of 1,500-foot candles has been selected. This illuminance level allows for a loss factor of two-thirds due to model surface scattering geometry, and dichroic filter light loss. The effective probe t-number of 125 accounts for remaining losses. The probe electronics package contains three video preamplifiers, together with deflection drive signals and sweep failure blanking. Beam current and acceleration controls, target potential, dynode gain, focus and alignment controls are external to the probe electronics package.

The system scan format is 30 frames per second, 2:1 interlace, 1,248 active scan lines per frame. The number of scan lines is selected to meet resolution requirements and to minimize Moire effects at the display kinescope. The video bandwidth of approximately 50 MHz permits resolution of 6 arc-minute detail (see Section 4.2.2.1 of Final Analytical Report).

Spatial frequency encoding by use of dichroic filter gratings ahead of the pickup tube imaging surface is used to convert scene chrominance into video signals. Two filter gratings are required for each tube with stripe densities of 820 stripes/in. With the red stop dichroic grating placed at right angles to the scanning beam, an amplitude modulated carrier frequency of 40 MHz is produced representing the levels of red detail in the viewed scene. The blue stop filter grating is placed at an angle of 49^{o} relative to the red filter stripes to provide a carrier frequency of

30 MHz for the blue scene information. A 23 MHz bandwidth is allocated for luminance to preserve the 6 arc-minute resolution performance, and a modulation bandwidth of 2.5 MHz is assigned to the chrominance carrier frequencies. The frequency spectrum for each video channel is therefore as shown in figure 3.6. By placing the blue passband next to the luminance, some high frequency components entering the blue band will not be easily detected since eye sensitivity in the blue spectral regions is low.

To obtain accurate color encoding over the total field requires good pickup tube response over the entire tube face at the filter spatial frequency. The spatial frequency chosen of 820 lines/inch corresponds to 2,000 TV lines for the 1.5-inch diagonal pickup tube. The pickup tube signal uses a decoding system as shown in the block diagram of figure 3.7 to separate the chrominance and luminance signals from the encoded video input. An electronic low pass filter covering a frequency band equal to the red and blue bandwidths is used to enable matrixing red, blue and luminance of equal bandwidths to obtain the green video component. The decoding system is contained in the TV Control System so that further processing in the CCTV system can be accomplished on the lower bandwidth signals. The wide bandwidth of the luminance signal is retained through the system and is delay matched to the chrominance prior to being displayed. The display electronics utilizes the wide bandwidth luminance signals to drive the cathodes of the display kinescopes guns while the color signals are applied as low bandwidth modulating signals to the grids of the appropriate kinescope guns.

The TV Control System contains master sync control electronics so that the sweeps and blanking signals supplied to each TV camera system and the signals to the CGI equipment are accurately synchronized. Also supplied to the camera electronics are electronic focus, beam current, target voltage, and other control and supply voltages. Processing circuits contained in the control system for each camera video signal include aperture correction, gamma correction, shading compensation, video gain control, keyed clamp, sync addition, and color decoding.

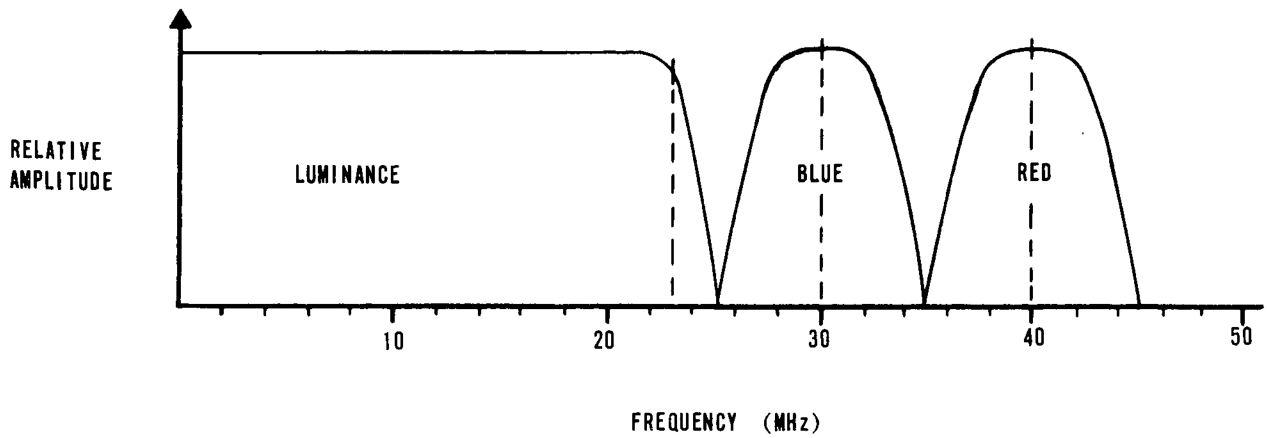


FIGURE 3.6 DECODING SYSTEM BLOCK DIAGRAM

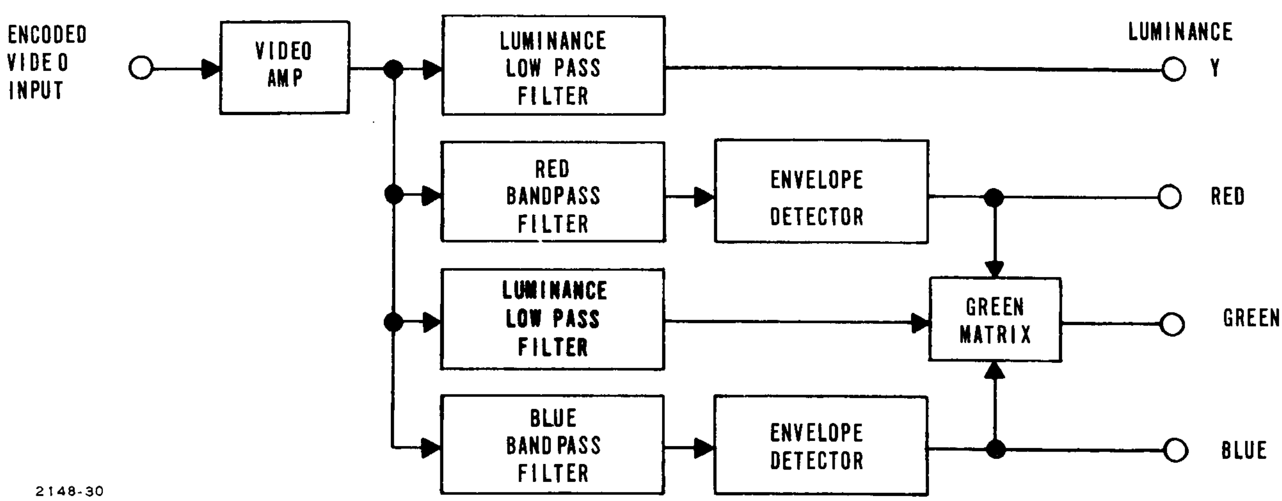


FIGURE 3.7 DECODING SYSTEM BLOCK DIAGRAM

A video switcher within the control system selects one of the four processed earth model video lines at the appropriate time in the mission as directed by the camera switching control signal from the computer interface. The actual switching transition is accomplished within a vertical blanking period to avoid picture breakup. Selection of test pattern video from the Maintenance Control and Test Station is also possible through commands on a Test and Maintenance signal input line. The test video can be presented on either output video line and is used for system alignment.

Status signals are supplied to the Maintenance Control and Test Station from the TV Control System for indicating malfunctions, operating modes, and active camera units. The capability for monitoring of camera video and control signals is also provided for aiding maintenance.

A keying and video processing system is recommended which accepts the video signals for the various scene elements combining and insetting them in such a manner that a realistic composite scene is produced.

After reviewing several TV techniques for combining images (see Section 5.0 of Final Analytical Report) it was determined that the self-keying method using luminance level provides the most practical and accurate method for combining scenes in the Shuttle Visual System.

A simplified block diagram of the recommended scheme is shown in figure 3.8. This represents the keying and processing of one video channel. Three keyers accept the luminance signals for earth, target and cloud video. When a preset threshold level within a keyer is exceeded during a horizontal scan, the complementary outputs of the keyer change states. The keyer outputs are then combined using logic gates G1, G2, and G3 to form the signals for switching the video signals with proper insetting priority using analog gates S1 through S4. The logic is such that target video takes priority over all other video and earth video has priority over star video. The video to be displayed in the composite scene is obtained at the outputs of the summing amplifiers. The chrominance signals in the system would actually be three separate lines of red, blue, and green video switched simultaneously, but are shown simplified as single lines in the diagram.

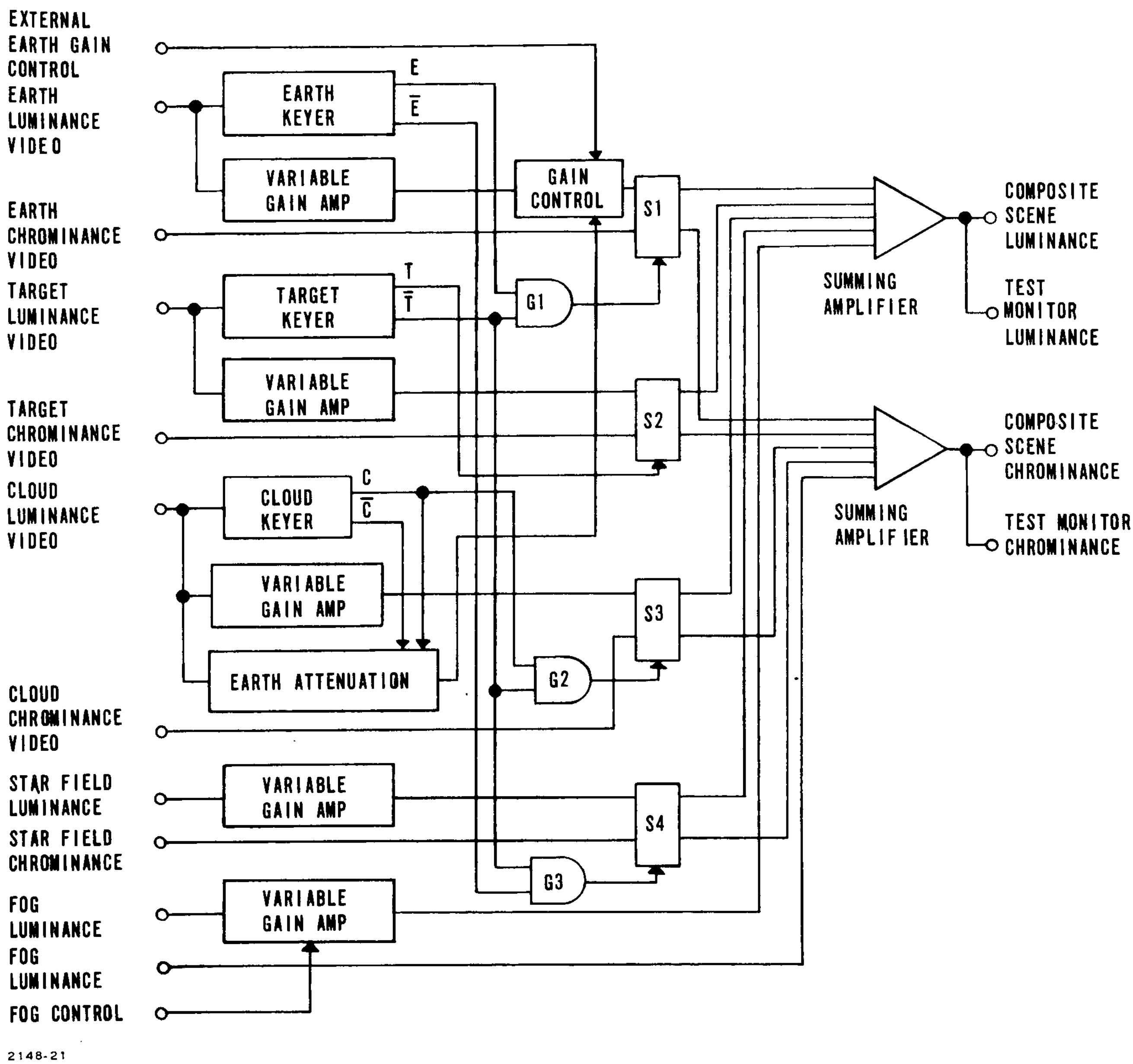


FIGURE 3.8 KEYING AND VIDEO PROCESSING SYSTEM

The cloud video which also contains sky, terminator and in some mission phases fog and artificial horizon is processed by a section of circuits noted as Earth Attenuation control. Low luminance levels below the cloud key threshold representing earth terminator produce a signal to the earth video gain control circuit giving attenuation in correspondence to terminator area luminance. A gradual change from night zone to day zone is produced across the terminator. When the luminance levels are above the key threshold, sky and clouds are presented to the output. As the luminance level of the cloud video increases representing increased cloud density, the earth video is again attenuated. The high density clouds therefore will mask out appropriate portions of the earth. For very light density clouds some earth features will be visible through the clouds.

External control signals from the computer interface are used for control of artificially-generated fog and attenuation of earth video. The artificially-generated fog is used during the ascent and re-entry phase when passing through clouds. A varying density white video display is presented. During re-entry, the earth video must be attenuated when the fog level increases. This is accomplished by the external gain control signal which changes in correspondence to the fog control signal.

The output video is supplied to the display switcher and also to the test station. Test and maintenance signals supplied to the TV keying and Video Processing System (not shown in figure 3.8) are used to provide manual external control of gain keying levels and switching signals.

Status and monitoring lines are brought out for the Maintenance Control and Test Station to aid alignment and maintenance.

3.3.7 Displays Equipment

The recommended displays equipment for the forward and aft fields are reflective edge registered non-pupil forming units with high-resolution shadow mask cathode ray tubes as input image sources. Individual units provide a total field of view of 50° horizontally by 37.5° vertically. In the case of the vertical field, the instantaneous vertical field of view is 28° with the eyepoint at the mirror center of curvature. The total vertical field of 37.5^{o} is revealed to the observer as the eyepoint is moved vertically from the center of curvature by $\pm 4"$. Also, as the eyepoint is moved inward along the mechanical axis of the mirror, the instantaneous vertical field increases. At a point 11" from the center of curvature, the instantaneous and total fields of view are equal and at a maximum of 37.5^{o}. In order to achieve the total vertical field of view, the display crts are allowed to intrude slightly into the upper portion of the available field. In this instance, and as a matter of MDEC experience, the increased vertical field out weighs the disadvantage of the presence of a small visible area of crt envelope, which is normally out of focus to the observer.

The recommended display device is an RCA type C74957 26-inch shadow mask color display tube. Each tube carries horizontally overlapped data in order that a continuous horizontal field may be presented when individual units are edge registered.

3.3.8 Forward Field Configuration

The geometric arrangement of the forward field displays equipment is shown in figure 3.9. Displays group ABC are assigned to the left eyepoint and group A'B'C' to the right. Four of the six units are active depending on probe azimuth bias position and CGI channel orientation, as follows:

Probe Position	Active Displays Group
1	CBAA'
2	BAA'B'
3	AA'B'C'

In all cases, identical data is displayed on A and A' display units. In probe positions 1, 2, and 3, some cross-viewing between left and right eyepoint positions is permitted. The instantaneous cross field of view in each case is 25^{o} horizontally by 18^{o} vertically.

The collimating mirrors of each group of displays form a continuous spherically-curved surface, and the beamsplitters are edge registered to minimize seams and seam shadows.

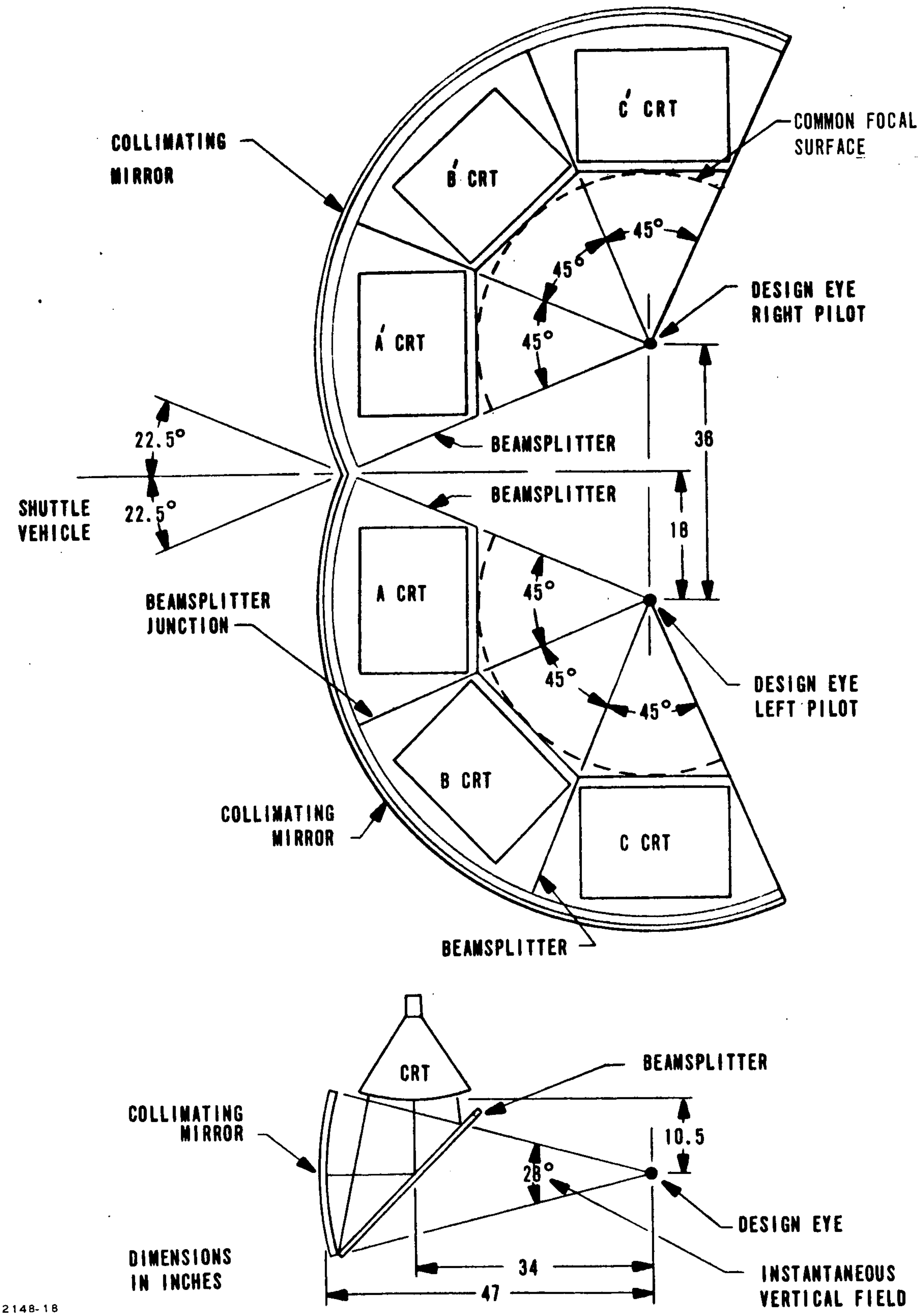


FIGURE 3.9 NON-PUPIL FORMING DISPLAY USING RCA DISPLAY CRTs

The image overlap provision is illustrated in figure 3.10. The probe and CGI data channels are overlapped by 5°, and individual cathode ray tubes display a horizontal field of 50°, of which exactly 45° is instantaneously observable. Thus, with the eyepoint coincident with the radius of curvature of the mirror, a continuous horizontal field of 135° is instantaneously observable. Although a computer ray-trace of two adjacent display segments using the approximate curvature of the recommended crt showed considerable field curvature (Analytical Study Report, Section 6.0). It appears questionable whether the visual effect of such curvature would be disturbing. Also, in the experimental dual package, field curvature, although present, was difficult to detect visually. A more definite analysis might indicate that some field flattening at image seams could usefully be incorporated by means of a low power refractive element in contact with the faceplate of the display tubes. The power of this element would be mainly effective at the edges of the cathode ray tube, in order to smooth field curvature discontinuities. The displays data overlap permits a small amount of head motion before image edge gaps become visible. Figure 3.11 illustrates the viewing geometry of off-axis head motion.

At a typical package seam, the beamsplitters overlap adjacent image surfaces. Consider points A and B. Due to input data overlap (figure 3.10)*, identical image information is located at A and B. With the eyepoint at P', point B only is visible. Since point A and B have the same angular direction and image information, head motion from P to P' can be accomplished with no visible image discontinuity. For head motion beyond point P', imagery from cathode ray tube A ceases to be visible, and a discontinuity in the form of dark vertical zone appears between cathode ray tube A and B imagery. The extent to which head motion can be permitted (distance PP') is wholly determined by the overlap geometry. In the recommended system, approximately ± 3 inches head motion is permitted.

*Note that crts A and B faceplates are shown to be slightly displaced for the purpose of the discussion. In practice they are optically continuous due to the folding action of the beamsplitter.

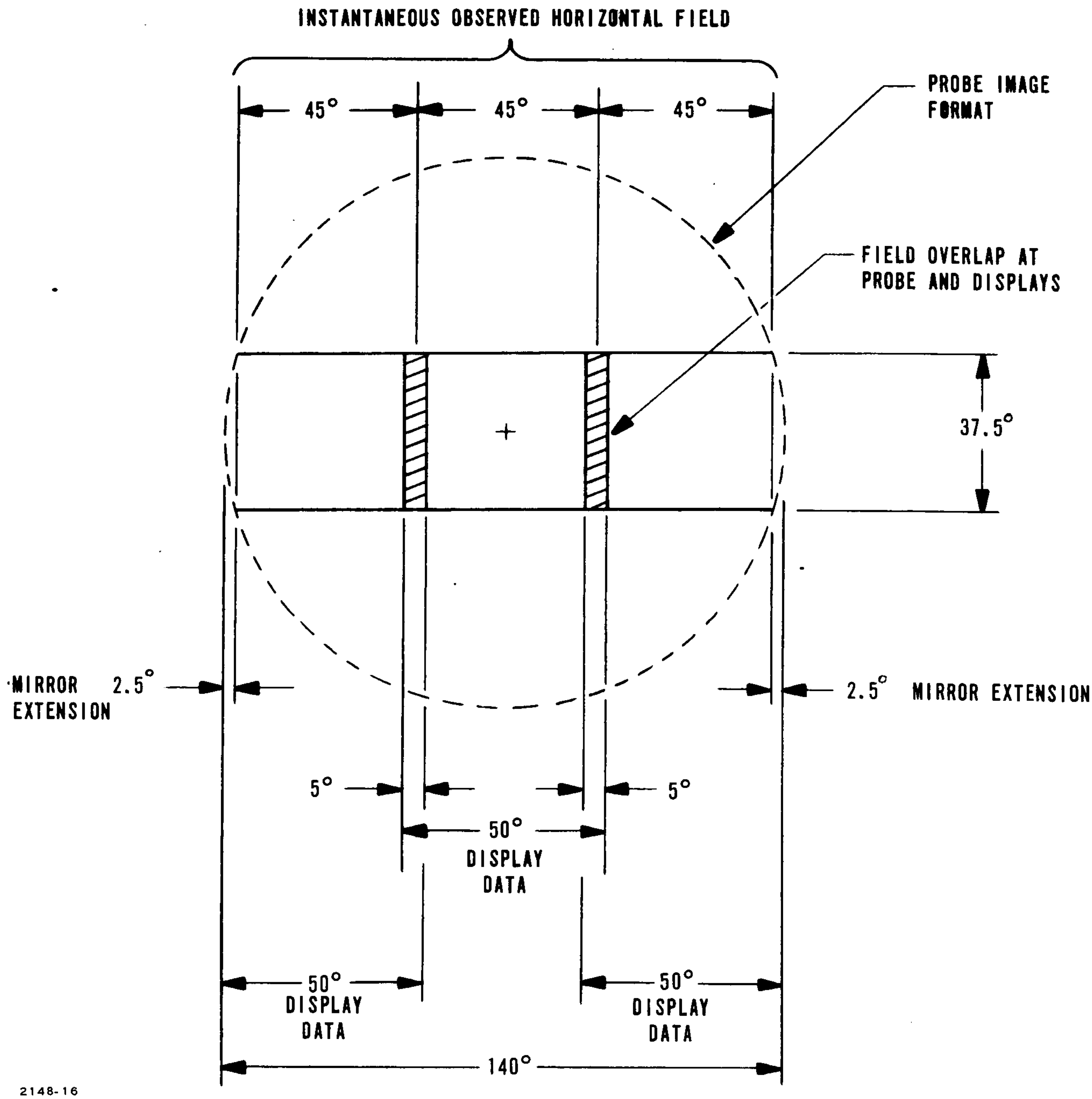


FIGURE 3.10 IMAGE OVERLAP FORMAT

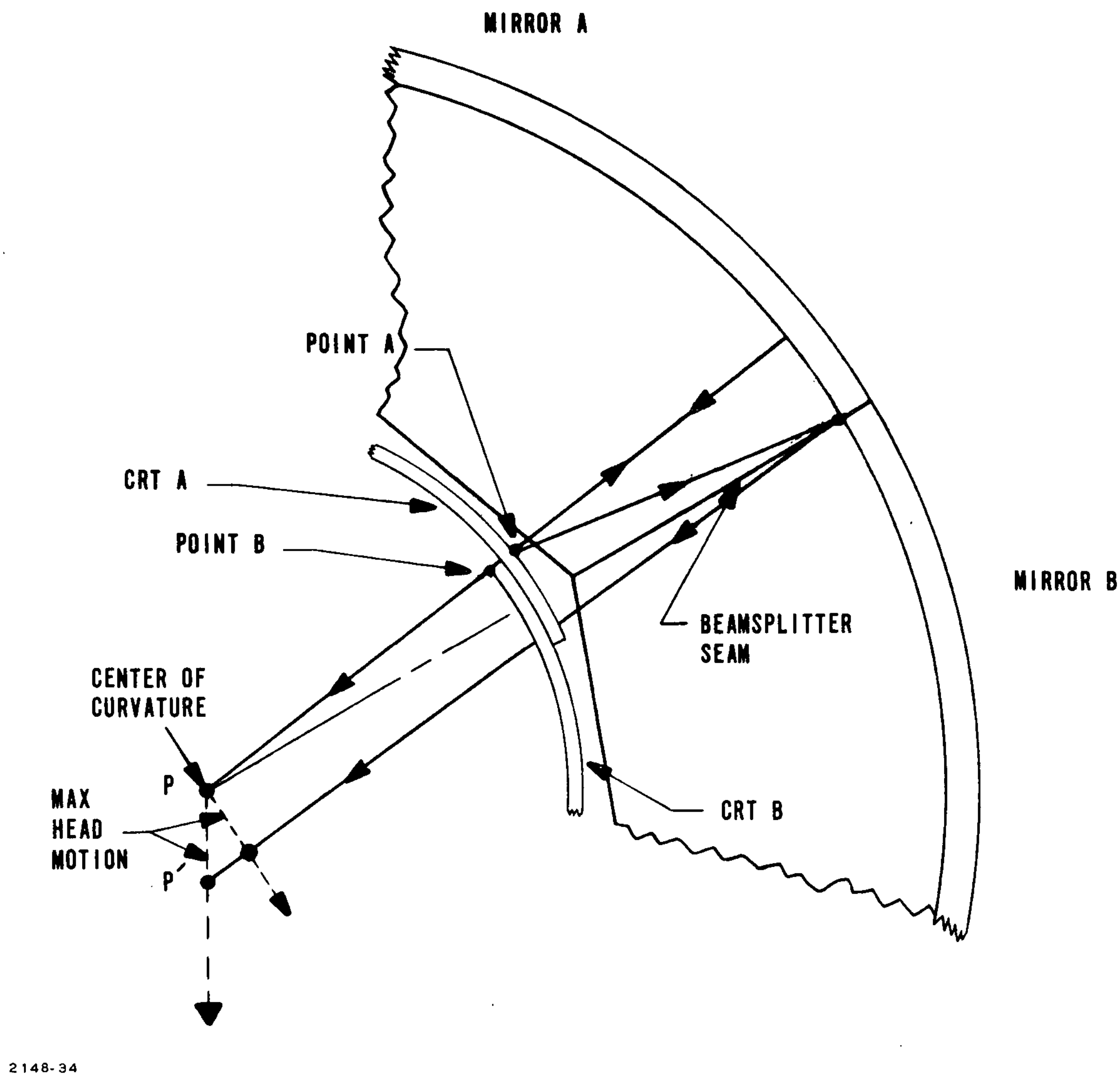


FIGURE 3.11 HEAD MOTION AND IMAGE OVERLAP

This is considered to be the best compromise in view of the following factors:

a. Structural cockpit members are likely to fall in the displays package seam zones.

b. The provisions of large amounts of image overlap complicates the optical design of the probe coupler.

c. The dark zones will appear in peripheral vision, and mainly under uncomfortable viewing conditions (head forward and rotated left or right).

3.3.9 Aft Field Configuration

The total field of view observable from the payload handling station eyepoints is limited only by the viewing cupola structural members, and approximates a one-half sphere. The payload handling specialist may also use the forward field during rendezvous operations. The aft field of view displays configuration must therefore be a compromise which involves both state-of-the-art displays limitations and the need to use forward field image sources in the aft field. This latter consideration leads to the selection of a three-channel displays configuration in order to hold the problem of image processing within manageable proportions.

The aft field displays may be distributed horizontally or vertically. The recommendation is a vertical configuration with a mechanism which translates and rotates the stack from an eyepoint position corresponding to rearward/reclined seat location (point A, figure 3.12) to the nominal aft viewing eyepoint (point B, figure 3.12). The transition event is keyed to the action of changing seat position. The transition event changes both CGI aft field channel orientation and the earth scene probe angular attitude. Point C is the real world furthest aft eye position during aft RMS operations.

In essence, the displays are transported to accommodate head motion of the order of 35 inches, and used on an area-of-interest basis. Thus, advantage is taken of the situation that in seat position A, the forward field is not available to the observer, and conversely the vertical field is restricted in position B. The anticipated operational viewing envelopes in the aft field are shown in Appendix A, figure 3.

The displayed data format and overlap conditions for the aft field displays are identical to the forward field units, and are as illustrated in figure 3.10.

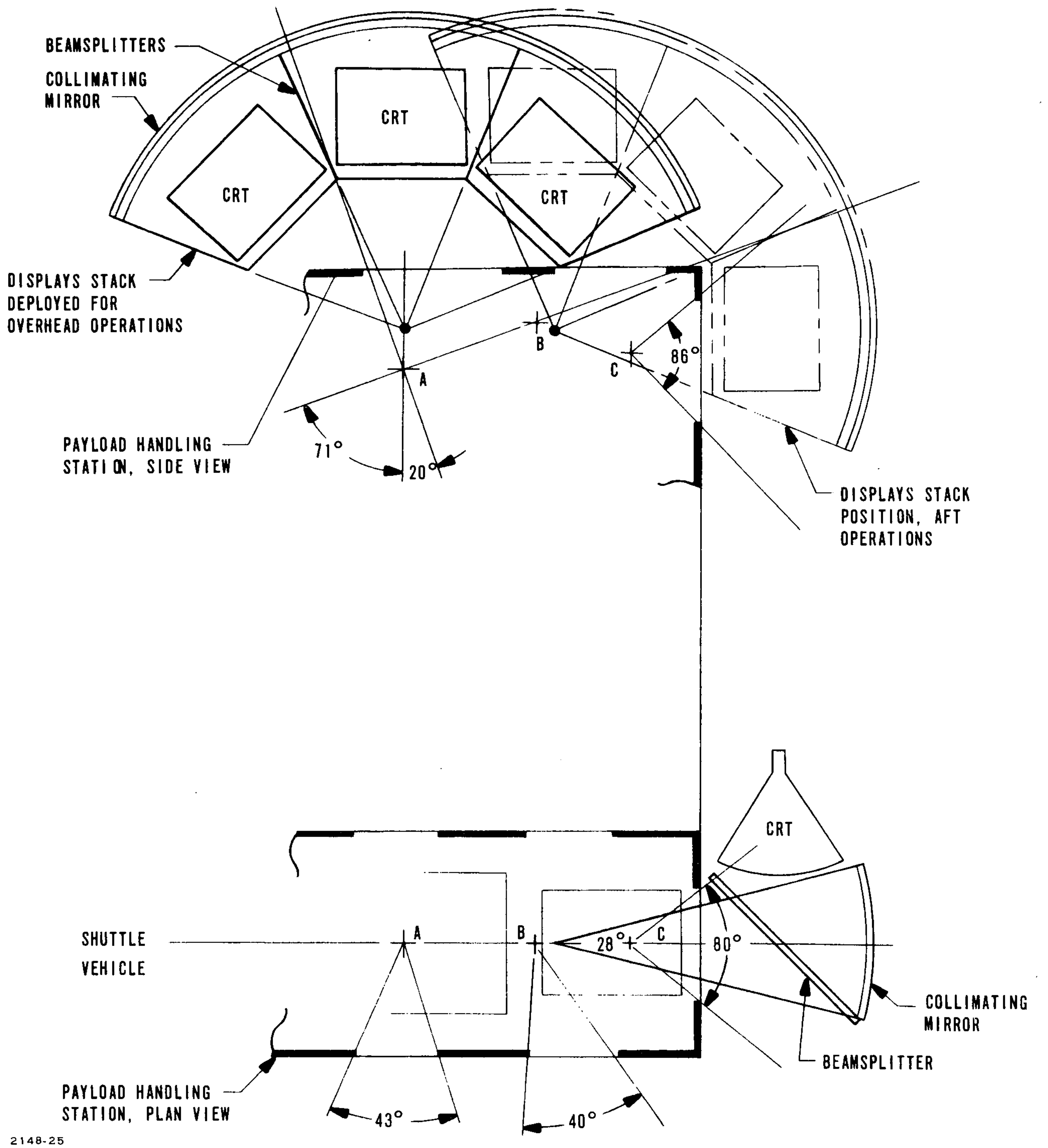


FIGURE 3.12 AFT DISPLAYS CONFIGURATION

3.3.10 Displays Equipment Characteristics

Mechanical:

The elements of the forward and aft display units are identical. Mechanical integration of the elements for each display unit is basically the same, with some variation on mechanical interface between forward and aft locations. The cathode ray tube and electronics are packaged conventionally. The single piece mirror is formed from either:

a. 1.25" acrylic sheet, draped, annealed and polished, or

b. .070" hard nickel electroformed from a suitable polished mandrel.

The beamsplitter is 1/4" crown glass plate polished to ten fringes per inch flatness. One surface carries a 50/50 beamsplitting layer. The other surface is treated with a single layer of magnesium fluoride antireflection coating. The mirror, beamsplitter and display unit chassis is an integral unit of torque box construction, total weight approximately 300 pounds. The total forward field displays equipment weight is approximately 1,850 pounds, including mechanical attachment hardware. The preferred attachment method is two strong points within the mission simulator cockpit shell, with the vertical load being absorbed by the motion platform.

Optical:

The principal optical characteristics of the integrated three-unit groups are as follows:

Field of View:	$135^{\circ} \times 28^{\circ}$ (instantaneous), $140^{\circ} \times 37.5^{\circ}$ (total)
Display Luminance:	15 foot-lamberts peak highlight 10 foot-lamberts average highlight
Display Resolution Element Angular Size:	Approximately 3 arc-minutes.
Display Chrominance:	See chromaticity data, Appendix A.
Resolution:	10 distinguishable black and white scales. System response optimized for maximum MTF at 6 arc-minutes.

Collimation:	No portion of the observed image closer than 60' from an eyepoint at the center curvature.
Geometric Distortion:	Not greater than $\pm 2\%$ in any individual unit, and not greater than $\pm 2\%$ cumulatively across the total field of view.

Electrical:

The display cathode ray tube electrical characteristics are as follows:

Video Bandwidth:	50 MHz
Scan Format:	
Lines Per Frame	1,357 total, 1,248 active
Frames Per Second	30
Interlace	2:1
Deflection Speeds:	
Horizontal	1.03 inches/usec
Vertical	1.02 inches/usec
Final Anode Voltage:	30 KV
Maximum Beam Current:	1,000 uA
Deflection Method:	Resonant Magnetic
Focus:	Electrostatic
Luminance (at 1,000 μA beam current):	50 foot-lamberts
Peak Luminance:	75 foot-lamberts
Resolution	900 TV lines

3.3.11 Computer Interface

A computer interface configuration consistent with the approach described in the Computer Complex Hardware Requirements Final Report MDC E0798 prepared by McDonnell Douglas Astronautics-East, is recommended.

In this approach, mini-computers act as buffers between simulation hardware and host computer, enabling data transfer to and from host computer to be done in continuous blocks at the beginning or end of a time frame. This minimizes the host computer interrupt processing. Reformatting of the data is also performed by the mini-computer in order to minimize the input/output burden on the host computer central processor.

The mini-computer interfaces with data conversion equipment which accesses and processes the input and output signals to and from the simulation hardware.

Interfacing signals for the visual system are all digital, and are processed along with the other simulation hardware signals by common I/O equipment. A simplified block diagram of the interface configuration is shown in figure 3.13.

A summary of the visual system interfacing signals is given in table 3.1, with a detailed listing given in table 3.2.

Positioning signals for the servo drives are in the form of two digital words (sine, cosine) for each drive. These are converted to synchro-type signals within the servo units. Where low update rate positioning commands can be utilized, lines are shared by two or three servo drive units with an address line providing the decoding command signals.

The data defining the visual characteristics of the scene elements generated by the CGI equipment is loaded into memory through peripheral equipment which forms part of the CGI system. Position, attitude and eyepoint locations for the CGI scene elements are computed by the host computer and supplied through the digital interface.

The total number of digital input bits for the visual system is 108 which can be multiplexed into 7 16-bit words. A total of 1,287 digital output bits are required which can be obtained from 81 16-bit words.

3.3.12 Facilities Requirements

The principal factors considered in the estimation of facilities requirements for the recommended base line system were as follows:

a. Floor area and ceiling height

b. Estimated thermal load

c. Cooling air requirements.

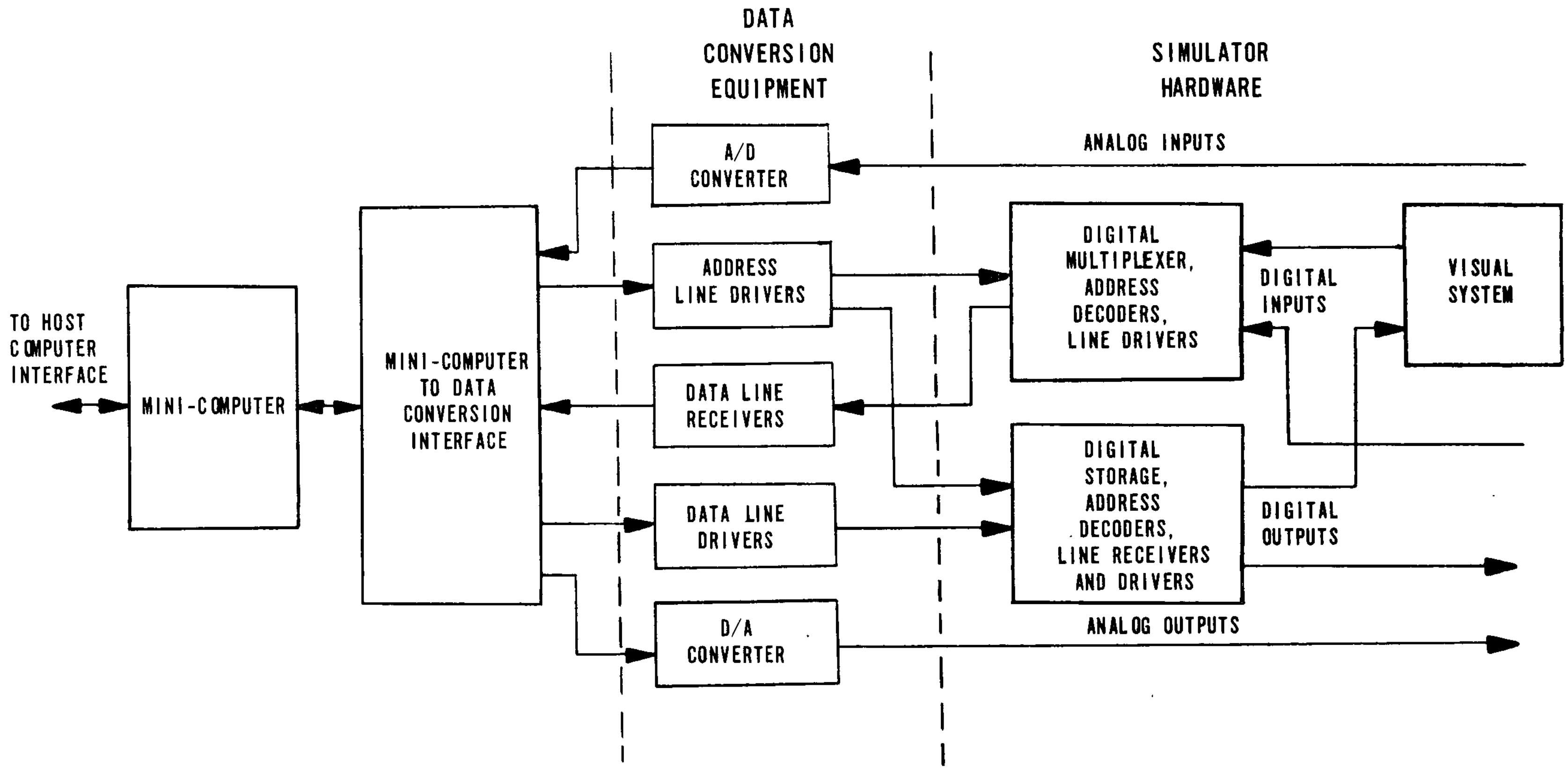


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FIGURE 3.13 VISUAL SYSTEM COMPUTER INTERFACE

TABLE 3.1

VISUAL SYSTEM INTERFACE SUMMARY

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
TERMINAL AREA MODEL		
LIGHTING CONTROL		3
ATTITUDE COMMANDS		96
ATTITUDE STATUS	3	
POSITIONING COMMANDS		38
POSITIONING STATUS	8	
LANDING LIGHTS		3
RUNWAY LIGHTS		7
SCHIEMPFLUG TILT		6
HIGH ALTITUDE MODEL		
LIGHTING CONTROL		3
ATTITUDE COMMANDS		96
ATTITUDE STATUS	3	
POSITIONING COMMANDS		38
POSITIONING STATUS	8	
SCHIEMPFLUG TILT		6
ORBITAL EARTH MODELS		
MODEL #1 ATTITUDE		96
MODEL #1 ATTITUDE STATUS	3	
MODEL #2 ATTITUDE		96
MODEL #2 ATTITUDE STATUS	3	
MODEL #1 POSITIONING COMMANDS		58
MODEL #1 POSITIONING STATUS	5	
MODEL #2 POSITIONING COMMANDS		58
MODEL #2 POSITIONING STATUS	5	
MODEL #1 SCHEIMPFLUG TILT		6
MODEL #2 SCHIEMPFLUG TILT		6

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TABLE 3.1 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
CLOUD/SKY/TERMINATOR SOURCE		
ASCENT SKY/CLOUD PROJECTOR		11
HIGH ALTITUDE CLOUD PROJECTOR	1	41
ORBITAL EARTH CLOUD PROJECTOR	1	41
TERMINATOR POSITIONING	1	36
HORIZON REFERENCE PROJECTOR		7
PROBE ATTITUDE		96
PROBE ALTITUDE		20
SCHIEMPFLUG TILT		6
STATUS SIGNALS	7	
COMPUTER GENERATED IMAGE SYSTEM		
RENDEZVOUS TARGET POSITION		18
RENDEZVOUS TARGET ATTITUDE		48
RENDEZVOUS TARGET BEACON		1
PAYLOAD POSITION		18
PAYLOAD ATTITUDE		48
RMS POSITIONING		132
RMS TV CAMERA EYEPOINT		50
RMS WRIST ADAPTOR/PAYLOAD	2	
STARFIELD REFERENCE		52
PAYLOAD HANDLING LIGHTS SELECT		3
CGI SYSTEM OFF LINE	1	
TV CONTROL SYSTEM		
CAMERA SWITCHING COMMANDS		3
TV KEYING AND VIDEO PROCESSING		
EARTH ATTENUATION		10
FOG LEVEL		10

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TABLE 3.1 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
DISPLAY SWITCHER		
DISPLAY SWITCHING COMMANDS		3
MAINTENANCE CONTROL AND TEST STATION		1
TEST MODE		
OPERATOR STATION		
VISUAL SYSTEM CONTROL SIGNAL	46	
VISUAL SYSTEM STATUS		14
CREW STATION		
CONTROL SIGNALS	11	
AFT DISPLAY POSITIONING		2
TOTAL	108	1287

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TABLE 3.2

VISUAL SYSTEM INTERFACE SIGNALS

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
<u>TERMINAL AREA MODEL</u>		
o LIGHTING CONTROLS		
DAY/NIGHT CONTROL		3
o ATTITUDE COMMANDS		
ROLL AXIS 2-16 BIT WORDS		32
PITCH AXIS 2-16 BIT WORDS		32
YAW AXIS 2-16 BIT WORDS		32
o ATTITUDE STATUS		
ROLL LIMIT OR STALL	1	
PITCH LIMIT OR STALL	1	
YAW LIMIT OR STALL	1	
o POSITIONING COMMANDS		
POSITION (X, Y, Z) 2-16 BIT WORDS		32
POSITION ADDRESS		2
SLEW		2
SLEW ADDRESS		2
o POSITIONING STATUS		
X LIMIT	1	
X STALL	1	
Y LIMIT	1	
Y STALL	1	
Z LIMIT OR CRASH	1	
Z STALL	1	
MANUAL OVERRIDE	1	
SLEW COMPLETE	1	
o LANDING LIGHTS		3
o RUNWAY LIGHTS		7
o SCHIEMPFLUG TILT		6

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
HIGH ALTITUDE MODEL		
o LIGHTING CONTROLS		
DAY/NIGHT CONTROL		3
o ATTITUDE COMMANDS		
ROLL AXIS 2-16 BIT WORDS		32
PITCH AXIS 2-16 BIT WORDS		32
YAW AXIS 2-16 BIT WORDS		32
o ATTITUDE STATUS		
ROLL LIMIT OR STALL	1	
PITCH LIMIT OR STALL	1	
YAW LIMIT OR STALL	1	
o POSITIONING COMMANDS		
POSITION (X, Y, Z) 2-16 BIT WORDS		32
POSITION ADDRESS		2
SLEW		2
SLEW ADDRESS		2
o POSITIONING STATUS		
X LIMIT	1	
X STALL	1	
Y LIMIT	1	
Y STALL	1	
Z LIMIT OR CRASH	1	
Z STALL	1	
MANUAL OVERRIDE	1	
SLEW COMPLETE	1	
o SCHIEMPFLUG TILT		6

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
ORBITAL EARTH MODELS		
o ATTITUDE COMMANDS #1 MODEL		
ROLL AXIS 2-16 BIT WORDS		32
PITCH AXIS 2-16 BIT WORDS		32
YAW AXIS 2-16 BIT WORDS		32
o ATTITUDE STATUS #1 MODEL		
ROLL LIMIT OR STALL	1	
PITCH LIMIT OR STALL	1	
YAW LIMIT OR STALL	1	
o ATTITUDE COMMAND #2 MODEL		
ROLL AXIS 2-16 BIT WORDS		32
PITCH AXIS 2-16 BIT WORDS		32
YAW AXIS 2-16 VIT WORDS		32
o ATTITUDE STATUS #2 MODEL		
ROLL LIMIT OR STALL	1	
PITCH LIMIT OR STALL	1	
YAW LIMIT OR STALL	1	
o POSITIONING COMMANDS #1 MODEL		
DRIVE POSITION (3 AXIS)		32
DRIVE POSITION ADDRESS		2
ALTITUDE 2-10 BIT WORDS		20
SLEW		2
SLEW ADDRESS		2
o POSITIONING STATUS #1 MODEL		
DRIVE A LIMIT OR STALL	1	
DRIVE B STALL	1	
DRIVE C STALL	1	
ALTITUDE LIMIT OR STALL	1	
SLEW IN PROCESS	1	

2148-4

TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
ORBITAL EARTH MODELS (CONTINUTED)		
o POSITIONING COMMANDS #2 MODEL		
DRIVE POSITION (3 AXIS) 2-16 BIT WORDS		32
DRIVE POSITION ADDRESS		2
ALTITUDE 2-10 BIT WORDS		20
SLEW		2
SLEW ADDRESS		2
o POSITIONING STATUS #2 MODEL		
DRIVE A LIMIT OR STALL	1	
DRIVE B STALL	1	
DRIVE C STALL	1	
ALTITUDE LIMIT OR STALL	1	
SLEW IN PROCESS	1	
o SCHEIMPFLUG TILT MODEL #1		6
o SCHEIMPFLUG TILT MODEL #2		6
CLOUD/SKY/TERMINATOR SOURCE		
o ASCENT SKY/CLOUD PROJECTOR		
ACTIVATE		1
INTENSITY 1-6 BIT WORD		6
SLIDE SELECT 1-4 BIT WORD		4
o HIGH ALTITUDE CLOUD PROJECTOR		
ACTIVATE		1
INTENSITY		6
FILM DRIVE POSITIONING 2-16 BIT WORDS		32
SLEW		2
SLEW COMPLETE	1	
o ORBITAL EARTH SCENE CLOUD PROJECTOR		
ACTIVATE		1
INTENSITY 1-6 BIT WORD		6
FILM DRIVE POSITIONING 2-16 BIT WORDS		32
SLEW		2
SLEW COMPLETE	1	

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
CLOUD/SKY/TERMINATOR SOURCE (CONTINUED)		
o TERMINATOR POSITIONING COMMANDS		
MASK DRIVE POSITION (2 AXIS) 2-16 BIT WORDS		32
MASK DRIVE ADDRESS		2
SLEW		2
SLEW COMPLETE	1	
o HORIZON REFERENCE PROJECTOR		
ACTIVATE		1
INTENSITY 1-6 BIT WORD		6
o PROBE ATTITUDE		
ROLL AXIS 2-16 BIT WORDS		32
PITCH AXIS 2-16 BIT WORDS		32
YAW AXIS 2-16 BIT WORDS		32
o PROBE ALTITUDE 2-10 BIT WORDS		20
o SCHEMPFLUG TILT		6
o STATUS SIGNALS.		
PROJECTOR FAIL	1	
FILM LIMIT	1	
TERM. MASK DRIVE STALL OR LIMIT	1	
PROBE ROLL LIMIT OR STALL	1	
PROBE PITCH LIMIT OR STALL	1	
PROBE YAW LIMIT OR STALL	1	
PROBE ALTITUDE LIMIT OR STALL	1	
COMPUTER GENERATED IMAGE SYSTEM		
o RENDEZVOUS TARGET POSITION		
(RELATIVE TO ORBITER EYEPOINT)		
POSITION DATA (X, Y, Z)		16
POSITION ADDRESS		2

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
COMPUTER GENERATED IMAGE SYSTEM (CONTINUED)		
o RENDEZVOUS TARGET ATTITUDE		
ROLL AXIS		16
PITCH AXIS		16
YAW AXIS		16
o RENDEZVOUS TARGET BEACON		1
o PAYLOAD POSITION		
(RELATIVE TO ORBITER EYEPOINT)		
POSITION DATA (X, Y, Z)		16
POSITION ADDRESS		2
o PAYLOAD ATTITUDE		
ROLL AXIS		16
PITCH AXIS		16
YAW AXIS		16
o RMS POSITIONING		
SHOULDER PITCH (ARM 1 & 2)		10
SHOULDER YAW (ARM 1 & 2)		10
ELBOW ROLL (ARM 1 & 2)		10
ELBOW YAW (ARM 1 & 2)		10
WRIST ROLL (ARM 1 & 2)		10
WRIST PITCH (ARM 1 & 2)		10
WRIST YAW (ARM 1 & 2)		10
MASS CENTER UPPER ARM		
(RELATIVE TO EYEPOINT)		
X DISPLACEMENT (ARM 1 & 2)		10
Y DISPLACEMENT (ARM 1 & 2)		10
Z DISPLACEMENT (ARM 1 & 2)		10
MASS CENTER LOWER ARM		
X DISPLACEMENT (ARM 1 & 2)		10
Y DISPLACEMENT (ARM 1 & 2)		10
Z DISPLACEMENT (ARM 1 & 2)		10
ARM ADDRESS		2

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
COMPUTER GENERATED IMAGE SYSTEM (CONTINUED)		
o RMS TV CAMERA EYEPOINT		
X DISPLACEMENT (ARM 1 & 2)		16
Y DISPLACEMENT (ARM 1 & 2)		16
Z DISPLACEMENT (ARM 1 & 2)		16
o SELECTED CAMERA ADDRESS		2
o RMS WRIST ADAPTOR/PAY LOAD CONTRACT	2	
o STARFIELD		
ORBITER EYEPOINT ATTITUDE		
ROLL AXIS		16
PITCH AXIS		16
YAW AXIS		16
STAR VISIBILITY		4
o PAYLOAD HANDLING STATION LIGHTS		3
o CGI SYSTEM OFF LINE	1	
TV CONTROL SYSTEM		
o CAMERA SWITCHING COMMANDS		3
TV KEYING AND VIDEO PROCESSING		
o EARTH ATTENUATION		10
o FOG LEVEL		10
DISPLAY SWITCHER		
o DISPLAY SWITCHER CONTROL		3
MAINTENANCE CONTROL AND TEST STATION		
o TEST MODE		1

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TABLE 3.2 (Cont)

SIGNAL DESCRIPTION	DIGITAL INPUT (BITS)	DIGITAL OUTPUT (BITS)
OPERATOR STATION (VISUAL PORTION)		
o VISIBILITY		
RANGE	10	
CEILING	10	
o CLOUD THICKNESS	10	
o RUNWAY LIGHTS		
APPROACH	4	
TOUCHDOWN ZONE	1	
STROBE	1	
VASI	1	
o FORWARD VIEW EYEPOINT SELECTION	2	
o RENDEZVOUS TARGET BEACON ON	1	
o VISUAL SYSTEM OPERABILITY CHECK	6	
o VISUAL SYSTEM STATUS		
TERMINAL AREA ON-LINE		1
HIGH ALTITUDE ON-LINE		1
ORBITAL EARTH #1 ON-LINE		1
ORBITAL EARTH #2 ON-LINE		1
CLOUD/SKY/TERM. ON-LINE		1
CGI SYSTEM ON-LINE		1
CREW STATION/EYEPOINT		3
RMS TV MONITOR SELECTED		2
RMS WRIST ADAPTOR/PAYLOAD CONTACT		2
VISUAL SYSTEM TEST MODE		1
CREW STATION (VISUAL PORTION)		
o RMS TV MONITOR SELECTED	2	
o PAYLOAD HANDLING LIGHTS SELECTED	4	
o LANDING LIGHTS SELECTED	3	
o PAYLOAD HANDLING SPECIALIST POSITION	2	
oAFT DISPLAY POSITIONING COMMANDS		2

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For the purpose of estimation, an equipment layout was assumed wherein all elements of image generation equipment were grouped together. Allowing for standard aisle-widths, workspace, and estimating equipment cabinet sizes, a total floor area of approximately 3,000 square feet is required. The basic equipment layout is shown in figure 3.14. Ceiling height varies from 45 feet in the high altitude model area, to 14 feet in the case of the low altitude, orbital earth models and sky/cloud unit. The ceiling height requirement for the CGI equipment including data base computer is 12 feet.

Total power requirements are estimated at 85 KVA assuming all models illuminated and operating. The single largest equipment power load is the low altitude model lighting system. In this instance, the estimate is based on the use of high efficiency cool white fluorescent tubes which output 10,000 lumens at 135 watts power consumption.

The sensible heat estimates for the system equipment components, and air mass flow requirements are shown in table 3.3. The zonal airflow requirements are based on a recirculating system with a $15^{\circ}F$ temperature differential across the heat exchanging equipment. Latent and sensible thermal loads due to occupancy, additional equipment and the external environment are not included in the airflow estimates. Overall, a cooling capacity of approximately 20 tons is required, excluding the factors noted above.

3.3.13 Technical Risk Areas

In order to meet the Recommended System total performance requirements, advances to the existing state of the art in certain equipment areas will be needed. In assessing the degree of technical risk associated with these advances, the following factors must be considered:

(1) The feasibility of advancing the state of the art sufficiently to improve an existing technology to the level determined by design requirements.

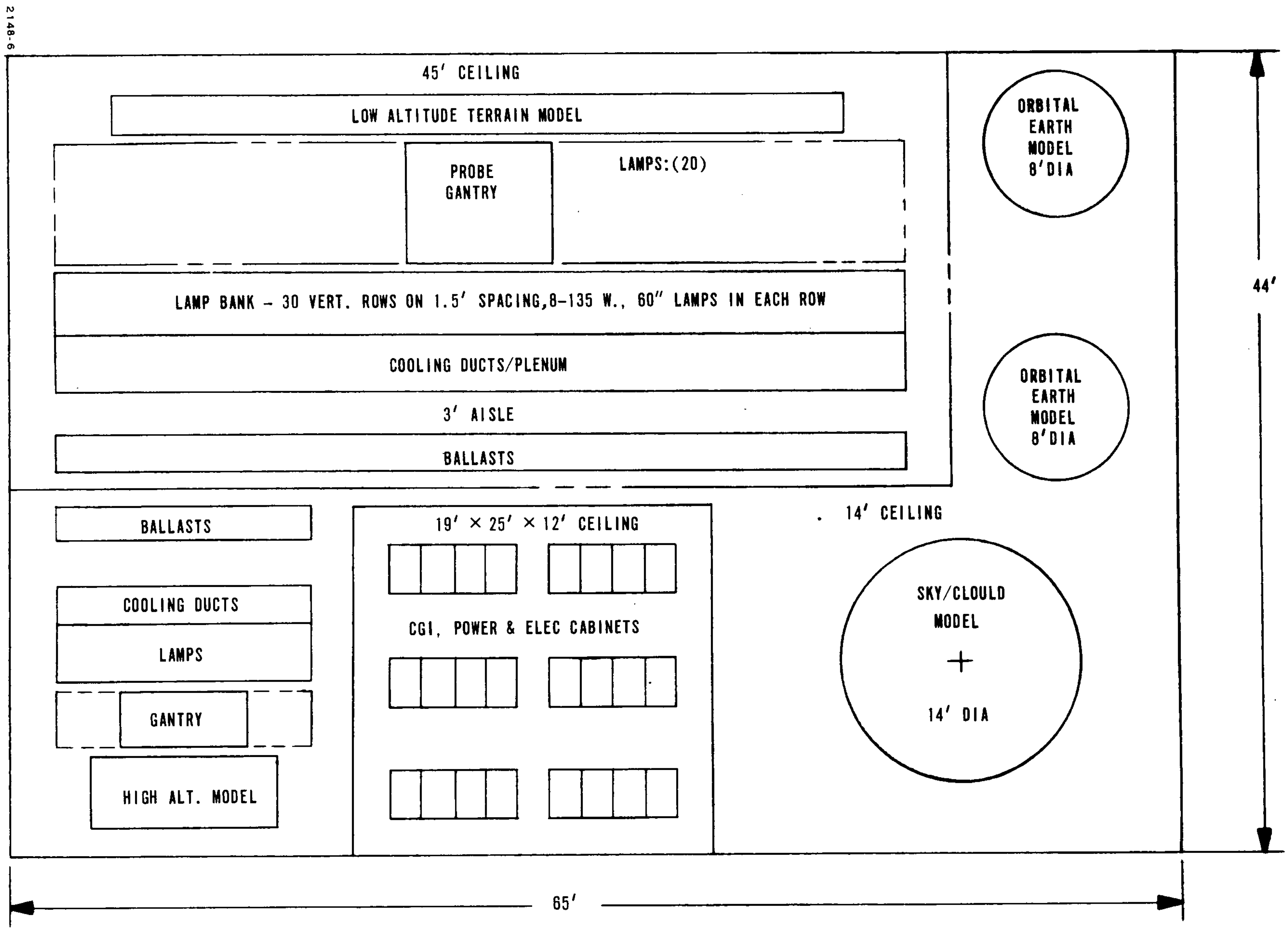

FIGURE 3.14 RECOMMENDED SYSTEM FACILITY REQUIREMENT

TABLE 3.3

THERMAL CLOUDS AND AIR MASS FLOW REQUIREMENTS

EQUIPMENT	THERMAL LOAD (BTU/HR)	COOLING AIR (CFM)
LOW ALTITUDE MODEL	134,700	8,200
HIGH ALTITUDE MODEL	7,750	475
SKY/CLOUD MODEL	28, 000	1,700
ORBITAL EARTH MODELS	7,950	500
CGI EQUIPMENT (TOTAL)	51,800	3,150
DISPLAY SUBSYSTEM	6,250	400
MAINTENANCE UNITS	1,250	75
DISPLAYS SWITCHING EQUIPMENT KEYING/VIDEO PROCESSOR CAMERA CONTROL UNITS TV MAINTENANCE EQUIPMENT	3,725	225
TOTAL:	241,425	14,725

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(2) The time factor involved in successfully completing the required state of the art advance.

The principal technical risk areas in the recommended system lie mainly in the TV/model image sensing and processing equipment. This is due to the limitations of the present day state of the art when considered in relation to the requirement for high resolution, wide field color scenes.

During the course of the study it was determined that optical probe and displays equipment segmentation was feasible, but significant light losses in the probe optical path led, of necessity, to the recommendation image isocon pick-up tubes. It was determined that further field splitting for the purposes of generating simultaneous RGB color signals would be impractical. Field sequential color was eliminated as suitable approach primarily because of bandwidth and image insetting difficulties. The recommendation of implementing color by single tube spatial frequency encoding involves technical risk due to the need for the development of an image isocon with 2,000 TV line response. (Near-term improvement in isocon resolution to 1,600 TV lines is anticipated.) It appears that the required improvement is unlikely to occur as a natural outgrowth in the technology since the main emphasis in single and dual-tube color systems development is directed toward the production of compact broadcast standards equipment.

Other technical risk areas in the Recommended System are as follows:

- <u>Optical probe field of view and point of closest approach</u>

A three-channel optical probe is the recommended sensing element for all model image generation equipment. An existing design was considered which has limitations on point of closest approach, and significant fall-off in performance at the edges of a 140° total field of view. Whereas a 2.5 mm approach point is required for the Low-Altitude model, the unmodified design permits 5 mm approach minimum. The evidence at this time is that by trading off the probe vertical field from 70° to 35°, and near-point focussing distance from 0.2 mm to 10 mm, a minimum approach distance of 2.5 mm can be obtained.

Refinements in the design, which are currently being pursued, are also expected to improve performance at the edges of the field.

- Model construction and decoration

The Low-Altitude model transport mechanism requires a vertical reach of 40 feet, which is significantly greater than that available in contemporary systems. There may be some risk in fabricating a sufficiently rigid structure. A suitable trade-off in this instance would be some reduction in lateral maneuvering freedom. (It should be noted that the definition of abort corridors may lead to the conclusion that a full mm x 20 mm maneuvering freedom is not required.)

The level of detail required in the earth, high altitude, and low altitude models is significantly higher than that normally provided by current hand-rendering techniques. In this case, the risk falls mainly in the area of cost contingency, and delivery schedule. Consultation with manufacturers in this specialized field indicates that there is no state of the art bar in providing the required level of detail.

4.0 ALTERNATE SYSTEMS

Four alternate systems are presented (figure 4.1) which depart from baseline system requirements. Alternate A is an approach in which fore and aft fields are functionally separated. Alternates B, C and D are systems of reduced complexity with progressively smaller fields of view. Since scene detail and brightness are considered to be the least 'tradable' of the perceptibility requirements, image quality is preserved at the expense of field of view in these systems. All of the alternates employ computed image generation techniques for the aft orbiter and RMS simulation.

4.1 ALTERNATE A: SEPARATED IMAGE GENERATION EQUIPMENT

In Alternate A, the essential components of the Baseline System are retained. The major difference between System A and the recommended system is that the aft field displays use computed imagery exclusively. Computed image targets may, however, be inserted in the forward field displays from the CGI system. The earth scene is provided by a computed earth horizon approximation, necessarily of limited realism due to the limitations of computed image techniques in generating curved shapes and amorphous texture.

Since the aft field displays scan format need not be compatible with the forward units, a different displays configuration and format may be used. Specifically, a $180^{\circ} \times 60^{\circ}$ three module fixed vertical stack is employed. The display device is the 25" shadow mask tube with an auxiliary relay mirror. The optical configuration of the stack is essentially as described in the Analytical Report, Section 6.0. The eyepoint location coincides with the intersection the exit pupil volumes of each display.

The advantages of this approach are as follows:

(1) Some reduction in complexity of video signal processing.

(2) Increased vertical and lateral field of view.

RECOMMENDED BASELINE SYSTEM

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT	IGE
ORBITAL EARTH	- 2 6' DIAMETER SPHERES, LANDMARK AREAS TO .001" DETAIL
HIGH ALTITUDE	- 800,000:1 SCALE 8' X 8' AREA COVERAGE 1000 X 1000 nmi
LOW ALTITUDE	- 40' X 40' MAP MODEL, 3000:1 SCALE
ORBITAL AND HIGH ALTITUDE CLOUDS, ASCENT SKY, TERMINATOR	- 3 TRANSPARENCY PROJECTORS AND TERMINATOR ASSEMBLY MASK o ASCENT SKY o ORBITAL CLOUD COVER o HIGH ALTITUDE CLOUDS
RENDEZVOUS, PAYLOAD, DOCKING TARGETS, AFT ORBITER BODY STAR FIELD RMS TV DISPLAYS	- 4 CHANNEL CGI SYSTEM, 4 LOOK POINTS. 3 ASSIGNED TO OBSERVER EYEPOINTS, 1 ASSIGNED TO PAYLOAD STATION TV DISPLAYS. CGI GENERATES KEYING SIGNALS, AND RMS ADAPTOR/PAYLOAD CONTACT EVENTS.

IMAGE SENSING AND PROCESSING

SENSING:

5 - 3 CHANNEL OPTICAL PROBES, TOTAL FIELD OF VIEW 140° X 37° PER UNIT.
3 POSITION AZIMUTH DETENT TO PERMIT PROBE ASSIGNMENT TO COMMANDER OR PILOT.
3 IMAGE ISOCONS PER PROBE. COLOR BY SPATIAL FREQUENCY ENCODING.

PROSCESSING:

50 MHz VIDEO CHANNELS, 150 MHz TOTAL BANDWIDTH PER PROBE TOTAL FIELD.
CHROMINANCE DATA EXTRACTED BY ELECTRONIC FILTERING.

ALL SCENE ELEMENTS MIXED AND INSET ELECTRONICALLY. CGI KEYING ACCEPTED BE VIDEO PROCESSING UNIT. RENDEZVOUS CGI TARGETS SWITCHED INTO FORWARD ACTIVE DISPLAYS. ORBITAL EARTH SCENE APPEARS IN AFT FIELD.

DISPLAYS

DISPLAY DEVICE

25" SHADOW MASK HIGH DEFINITION CRT, RESONANT 1357 LINE DEFLECTION SYSTEM, 4:3 ASPECT RATIO. 900 TV LINE RESOLUTION IN CENTER FIELD.

FORWARD DISPLAYS PACKAGE

SIX REFLECTIVE OPTICS UNITS, EDGE REGISTERED, THREE PER FORWARD EYEPOINT. 4 DISPLAY UNITS ACTIVE AT ANY ONE TIME, WITH LINE-OF-SIGHT EITHER FORWARD, BIASED INBOARD, OR OUTBOARD.

AFT DISPLAYS PACKAGE

3 EDGE REGISTERED UNITS VERTICALLY STACKED. MECHANICAL ASSEMBLY TO ROTATE DISPLAYS STACK FROM OVERHEAD VIEW SEAT POSITION TO NOMINAL SEAT POSITION. LINE OF SIGHT TRACKED BY CGI EQUIPMENT TO MODIFY CHANNEL CONTENT IN ACCORDANCE WITH LINE-OF-SIGHT DIRECTION.

2148-27 AFT DISPLAYS ALSO RECEIVE EARTH SCENE FROM ORBITAL EARTH MODEL.

FIGURE 4.1 SUMMARY OF BASELINE AND ALTERNATE SYSTEMS (SHEET 1 OF 5)

ALTERNATE A

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT	IGE
ORBITAL EARTH	- 2 6' DIAMETER SPHERES LANDMARK AREAS TO .001" DETAIL
HIGH ALTITUDE	- 800,000:1 SCALE, 8' X 8' AREA, COVERAGE 1000 X 1000 nmi
LOW ALTITUDE	- 40' X 40' MAP MODEL, 3000:1 SCALE
ORBITAL AND HIGH ALTITUDE CLOUDS, ASCENT SKY, TERMINATOR	- 3 TRANSPARENCY PROJECTORS AND TERMINATOR ASSEMBLY MASK o ASCENT SKY o ORBITAL CLOUD COVER o HIGH ALTITUDE CLOUDS
RENDEZVOUS, PAYLOAD DOCKING TARGETS, AFT ORBITER BODY STAR FIELD RMS TV DISPLAYS	- 4 CHANNEL CGI SYSTEM, 4 LOOK POINTS. 3 ASSIGNED TO OBSERVER EYEPOINTS, 1 ASSIGNED TO PAYLOAD STATION TV DISPLAYS. CGI GENERATES KEYING SIGNALS, AND RMS ADAPTOR/PAYLOAD CONTACT EVENTS.

IMAGE SENSING AND PROCESSING

SENSING:

5 - 3 CHANNEL OPTICAL PROBES, TOTAL FIELD OF VIEW 140° X 37° PER UNIT.
3 POSITION AZIMUTH DETENT TO PER PERMIT PROBE ASSIGNMENT TO COMMANDER OR PILOT.
3 IMAGE ISOCONS PER PROBE. COLOR BY SPATIAL FREQUENCY ENCODING.

PROCESSING:

IN ALTERNATE SYSTEM A, THE FORWARD AND AFT FIELDS ARE FUNCTIONALLY SEPARATED. IN THE FORWARD FIELD, THE ORBITAL EARTH, HIGH AND LOW ALTITUDE SCENES ARE PROVIDED AS IN THE RECOMMENDED BASELINE SYSTEM.

THE AFT FIELD EMPLOYS CGI TECHNIQUES EXCLUSIVELY. PUPIL FORMING DISPLAY UNITS, 3 TOTAL, PROVIDE A FIXED, VERTICALLY STACKED 180° X 60° DISPLAY. AN EARTH HORIZON TRACE IS PROVIDED USING AN EDGE APPROXIMATION. NO FORWARD FIELD IMAGERY APPEARS IN THE AFT FIELD. RENDEZVOUS TARGETS ORIGINATED BY THE CGI EQUIPMENT ARE HOWEVER, INSERTED IN THE APPROPRIATE FORWARD FIELD GROUP.

THE AFT FIELD DISPLAYS EMPLOYS THE RECOMMENDED DISPLAY TUBE WITH A RELAY MIRROR WHICH INPUTS AN AERIAL IMAGE TO THE EYEPIECE MIRRORS. (APPROACH AS DISCUSSED IN PUPIL-FORMING OPTICS SECTIONS OF ANALYTICAL REPORT).

DISPLAYS

DISPLAY DEVICE

25" SHADOW MASK HIGH DEFINITION CRT, RESONANT 1357 LINE DEFLECTION SYSTEM; 4:3 ASPECT RATIO. 900 TV LINE RESOLUTION IN CENTER FIELD.

FORWARD DISPLAYS PACKAGE

SIX REFLECTIVE OPTICS UNIT, EDGE REGISTERED, THREE PER FORWARD EYEPOINT. 4 DISPLAY UNITS ACTIVE AT ANY ONE TIME, WITH LINE-OF-SIGHT EITHER FORWARD OR BIASED INBOARD, OR OUTBOARD.

2148-2

FIGURE 4.1 SUMMARY OF BASELINE AND ALTERNATE SYSTEMS (SHEET 2 OF 5)

ALTERNATE B

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT	IGE
ORBITAL EARTH	- SINGLE 6' DIAMETER EARTH SPHERE WITH 55% FIXED CLOUD COVER DECORATION, DETAIL TO .005" , ORBITS LIMITED TO ± 45° INCLINATION TO EQUATOR.
HIGH ALTITUDE	- 800,000:1 SCALE MODEL, 8' X 8' AREA 1000 X 1000 nmi.
HIGH ALTITUDE CLOUDS, ASCENT SKY, TERMINATOR	- 2 TRANSPARENCY PROJECTOR, TERMINATOR MASK, o ASCENT SKY o HIGH ALTITUDE CLOUDS
LOW ALTITUDE SCENE	- 40' X 30 ' 3000:1 SCALE MAP MODEL 20 X 15 nmi MANUEVERING FREEDOM.
RENDEZVOUS, PAYLOAD DOCKING TARGET, AFT ORBITER BODY, STAR FIELD	- 3 CHANNEL CGI, TWO LOOKPOINTS ASSIGNABLE TO EITHER FORWARD OR AFT EYEPOINTS, IN AFT FIELD, ONE CHANNEL SWITCHABLE TO TV DISPLAYS AT PAYLOAD STATION

IMAGE SENSING AND PROCESSING

SENSING:

4-2 CHANNEL OPTICAL PROBES, TOTAL FIELD OF VIEW 94° X 37° PER PROBE, 2 POSITION AZIMUTH DETENT (COMMANDER OR PILOT QUARTER WINDOWS) 2-TUBE COLOR IMPLEMENTATION, 1 TUBE LUMINANCE, 1 TUBE SPATIAL FREQUENCY ENCODED CHROMINANCE. SILICON DIODE VIDICON SENSORS.

PROCESSING:

AS IN RECOMMENDED BASELINE SYSTEM

DISPLAYS

DISPLAY DEVICE:

25' SHADOW MASK CRT, 1357 LINE OPERATION, 900 TV LINE RESOLUTION IN CENTER FIELD.

FORWARD DISPLAY OPTICS:

4 REFLECTIVE OPTICS UNITS, EDGE REGISTERED, NON PUPIL FORMING AND OVERLAPPED, TWO PER FORWARD FIELD EYEPOINT, THREE UNITS ACTIVE AT ANY ONE TIME.

AFT DISPLAYS:

3 EDGE REGISTERED PUPIL FORMING, VERTICALLY STACKED UNITS. ORBITAL EARTH HORIZON AND TERMINATOR AVAILABLE IN CENTER AND LOWER CHANNEL ONLY. UPPER CHANNEL SWITCHABLE TO RMS TV MONITORS.

2148-20

FIGURE 4.1 SUMMARY OF BASELINE AND ALTERNATE SYSTEMS (SHEET 3 OF 5)

ALTERNATE C

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT	IGE
ORBITAL EARTH/TERMINATOR	- 3 TRANSPARENCY PROJECTION AND TERMINATOR MASK MECHANISM AS IN RECOMMENDED SYSTEM
ASCENT SKY	
HIGH ALTITUDE SCENE	

NOTE: EARTH MODELS AND HIGH ALTITUDE MODELS DELETED. ORBITAL EARTH AND HIGH ALTITUDE SCENE VISUAL CUES DERIVED FROM CLOUD PACKAGE PROJECTOR.

RENDEZVOUS, PAYLOAD DOCKING TARGETS, AFT ORBITOR BODY, STAR FIELD	- 3 CHANNEL CGI SYSTEM.
LOW ALTITUDE EARTH SCENE	- 3000:1 SCALE MODEL 40 X 30 FT 20 X 15 nm MANUEVERING FREEDOM.

IMAGE SENSING AND PROCESSING

SENSING:

2 - 2 CHANNEL OPTICAL PROBES, TOTAL FIELD OF VIEW 94° X 37° PER PROBE, 2 POSITION AZIMUTH DETENT (COMMANDER OF PILOT QUARTER WINDOWS) 2 - TUBE COLOR IMPLEMENTATION, 1 TUBE LUMINANCE, 1 TUBE SPATIAL FREQUENCY ENCODED CHROMINANCE. SILICON DIODE VIDICON SENSORS.

PROCESSING:

AS IN RECOMMENDED BASELINE SYSTEM

DISPLAYS

DISPLAY DEVICE:

25" SHADOW MASK CRT 1357 LINE OPERATION, 900 TV LINE RESOLUTION IN CENTER FIELD

FORWARD DISPLAY OPTICS:

4 REFLECTIVE OPTICS UNITS, EDGE REGISTERED, NON PUPIL FORMING AND OVERLAPPED, TWO PER FORWARD FIELD EYEPOINT, THREE UNITS ACTIVE AT ANY ONE TIME.

AFT DISPLAYS:

3 EDGE REGISTERED NON PUPIL FORMING, VERTICALLY STACKED UNITS. ORBITAL EARTH HORIZON AND TERMINATOR AVAILABLE IN CENTER AND LOWER CHANNEL ONLY. UPPER CHANNEL SWITCHABLE TO RMS TO MONITORS.

2148-17

FIGURE 4.1 SUMMARY OF BASELINE AND ALTERNATE SYSTEMS (SHEET 4 OF 5)

ALTERNATE D

IMAGE GENERATION EQUIPMENT

SCENE ELEMENT:	IGE
ORBITAL EARTH/TERMINATOR	– 3 TRANSPARENCY PROJECTION AND TERMINATOR MASK MECHANISM AS IN RECOMMENDED SYSTEM
ASCENT SKY	
HIGH ALTITUDE SCENE	
LOW ALTITUDE EARTH SCENE	– OFF-THE-SHELF TV MODEL SYSTEM; 2000:1 SCALE MODEL 43' X 15' (14 X 5 nmi MANUEVERING FREEDOM).
RENDEZVOUS, PAYLOAD, DOCKING TARGETS, AFT ORBITOR BODY, STAR FIELD	– 2 CHANNEL CGI SYSTEM; 1 CHANNEL AT AFT NOMINAL EYEPOINT 60° X 60° FIELD OF VIEW, 1 CHANNEL ASSIGNED TO RMS TV DISPLAY.

IMAGE SENSING AND PROCESSING

SENSING:

2 SINGLE CHANNEL OPTICAL PROBES. 3 – TUBE SIMULTANEOUS COLOR. 3 PLUMBICON TUBES IN LOW ALTITUDE MODEL, 3 SILICON DIODE VIDICONS IN HIGH ALTITUDE/ORBITAL SCENE PACKAGE

PROCESSING

CGI RENDEZVOUS TARGETS ELECTRONICALLY INSET INTO FORWARD FIELD. EARTH AND STAR FIELD HORIZON AND ORBITAL EARTH SWITCHED INTO FORWARD FIELD DURING APPROPRIATE MISSION PHASE.

DISPLAYS

DISPLAY DEVICE

25" SHADOW MASK HIGH RESOLUTION DISPLAY TUBE, 1357 LINE OPERATION, 900 TV LINE RESOLUTION IN CENTER FIELD.

FORWARD DISPLAY OPTICS

2 REFLECTIVE OPTICS PACKAGES, SIMULTANEOUSLY OPERATED WITH IDENTICAL DATA AT COMMANDER AND COPILOT EYEPOINTS.

AFT DISPLAY OPTICS

2148-36 1 60° X 60° PUPIL FORMING SYSTEM AT NOMINAL EYEPOINT.

FIGURE 4.1 SUMMARY OF BASELINE AND ALTERNATE SYSTEMS (SHEET 5 OF 5)

The disadvantages are as follows:

(1) The increased field of view is obtained by trading both scene resolution (20% degradation approximately) and scene brightness (from 10.0 to 3.0 ft. lamberts highlight brightness).

(2) Earth scene realism reduced.

4.2 ALTERNATES B, C AND D: REDUCED FIELD OF VIEW

In these alternates the scope of the simulation is progressively reduced. Systems B and C use a two-channel optical probe, the coupler design of which is suggested in figure 4.2. Each of the individual channels is split into chrominance and luminance fields, and one-inch silicon diode vidicons are used as sensors. The use of a field splitting mirror introduces vignetting such that the vidicon target illuminance falls off from the center to the edge of each field by 50%. The combination of probe t-number, magnification and beamsplitter losses is such that the model illuminance levels recommended in the Baseline System could be used.

The electrical characteristics of the associated CCTV system for a two channel approach are as follows:

Pickup tube characteristics:	Silicon diode vidicon, GE type Z 7975 HR 1,200 TV lines center field resolution.
Scan format:	1,225 scan lines, 30 frames/sec 2:1 interlace.
Video bandwidth:	45 mhz, 30 db S/N ratio at 0.1 foot-candles highlight illuminance.

Alternate D is the minimum system compatible with the provision of all mission cues. The orbital and high altitude earth scenes, cloud cover and terminator are provided by the projection package which provides variable cloud cover in the Baseline System. An off-the-shelf TV/model system is used for landing, take-off and ferry operations. An advanced CCTV camera system is used to upgrade the displayed image quality of the standard system.

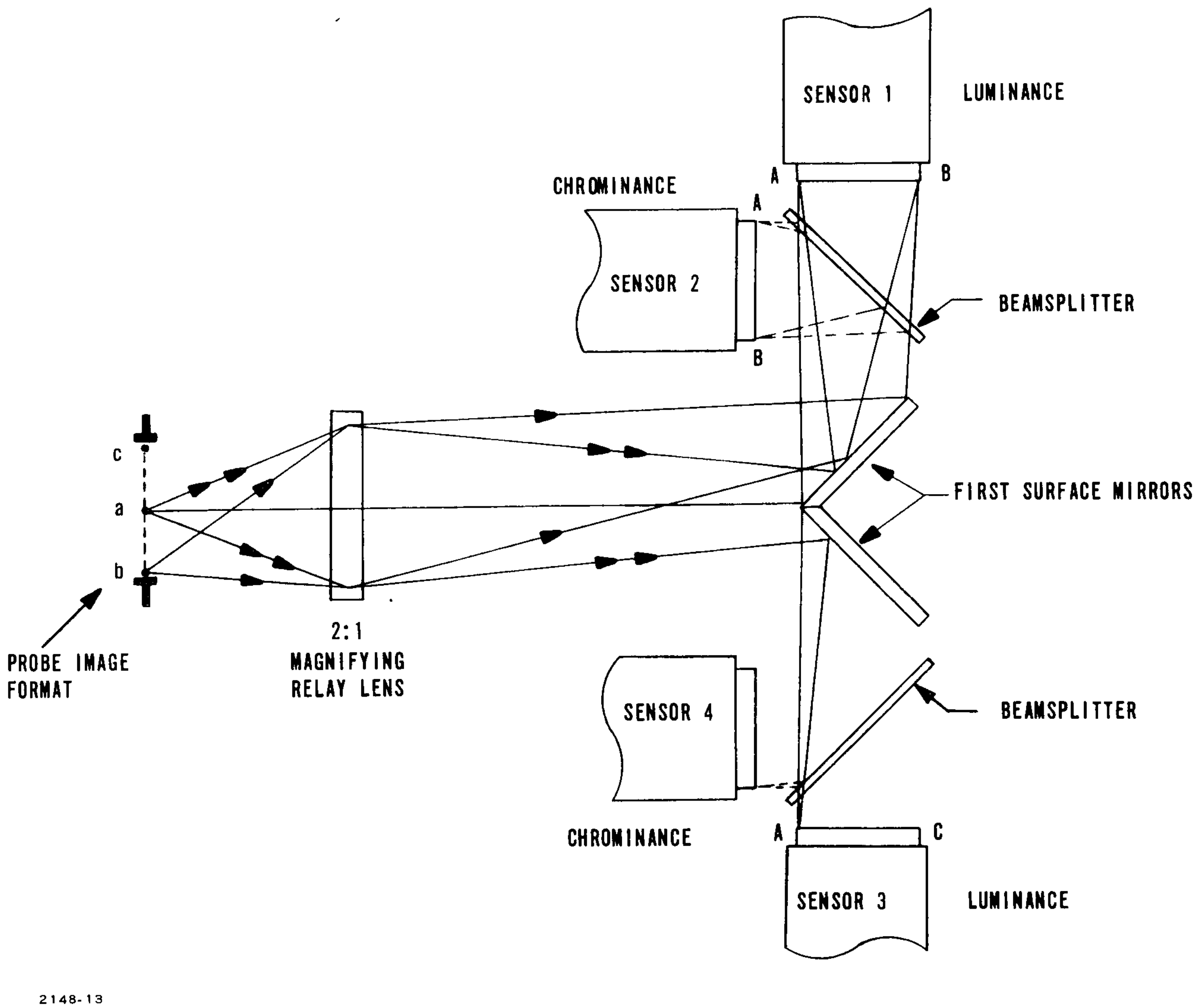


FIGURE 4.2 ALTERNATE TWO CHANNEL PROBE CONFIGURATION

5.0 BASELINE SYSTEM EQUIPMENT SPECIFICATION

5.1 GENERAL

The scope of the following specifications includes the image generation, sensing, and displays equipment of a high quality visual simulation system which when integrated, will form part of the Shuttle Mission Simulator. The intended application of the visual system is the provision of a continuous simulation of out-the-window scenes for training purposes during all of the Shuttle Mission phases from launch, on-orbit, re-entry and landing. The elements of the system are as follows:

- Two synchronously driven orbital earth models, a high altitude terrain model, and a low altitude landing/takeoff model.

- Image generation equipment for the simulation of variable orbital and high altitude cloud cover, earth terminator and ascent sky scenes.

- Computer generated image equipment to provide aft orbiter scenes, rendezvous targets, star field, and the simulation of real-time remote manipulator arm operation.

- A wide band color closed circuit television system with signal insetting mixing and fading capability. Five articulated optical probes sense the model image generation equipment.

- Non pupil-forming edge-registered displays using high resolution shadow mask cathode ray tubes.

- Maintenance and control equipment for monitoring, adjusting, and testing displaying image quality in on-line and off-line equipment operational modes.

5.2 DETAILED EQUIPMENT SPECIFICATIONS

5.2.1 Image Generation Equipment

5.2.1.1 Orbital Earth

Two orbital earth models with associated mounting and drive mechanisms shall be provided. The sphere shall accommodate the simulation of East-West orbits with inclinations in the range $\pm 45^{\circ}$ geographical latitude. For orbital inclinations outside this range, provision for automatic transitioning between both models shall be made to accommodate the simulation of continuous high inclination orbits up to and including South polar orbital inclination. The sphere mounts shall be arranged such that no part of the mount mechanism is visible to the sphere optical sensors.

The models shall be scaled at $6.96 \times 10^{6}:1$ and realistically decorated in color with non-relief continental land masses, seas, and appropriate topographical features including deserts, forests, and ice caps. Transitions between clearly defined topological features (e.g., terrain and seas demarkation) shall be modelled with maximum attention to edge sharpness. Such transitions shall be modelled with edge transitions of no more than .01 inches between pigments and/or emulsions. Maximum use shall be made either directly or indirectly of satellite reconnaissance and earth resources photography in the preparation of the models. In particular, circular landmarks areas (50 total) of 1.0 inches diameter on the model surface shall be prepared from photo-reconnaissance data with resolution element size not greater than 300 feet, and transferred to the model surface, with not more than 50% resolution degradation. The geographical accuracy of transferred landmark data shall not be less than $\pm 0.1^{\circ}$ in latitude and longitude.

Model construction shall be sufficiently accurate and rigid to meet the static and dynamic positioning requirements stated in table 5.1. The use of synthetic resins and electroforming processes shall be investigated as means of producing model substrate materials. Each model shall be provided with a stationary conical keying mask which exposes a model surface area corresponding to a 60° geocentric angle. The mask shall be fixed in close proximity with the model surface, and generate luminance transitions between the model surface and mask interior for the purposes

TABLE 5.1
ORBITAL EARTH MODEL TOLERANCES AND LIMITS

Orbital Earth Model

Item	Requirement
Model Scale*	6.967×10^6:1
Model Sphericity	$\pm$ 0.01" in all directions
Model Diameter	72" $\pm$ 0.03"
Static and Dynamic Positioning Accuracy	$\pm$ 0.1° maximum combined error
Repeatability	Static positioning accuracy repeatable to $\pm$ 0.5° maximum combined error.
Velocity	Each angular drive mechanism shall be capable of a range of 0° to 5° per minute rotational velocity, independent of all other drive mechanisms.
Acceleration	Each drive mechanism shall be capable of sustained acceleration of $\pm$ $2^{\circ}/\text{min}^2$ over a velocity range of 0 to 4.5°/minute.
Camera Transport Mechanism	Excursion (Z only): $\pm$ 3.09" Velocity: $0 \pm 0.2 \times 10^{-3}$ inches/sec with $\pm$ 0.1" sec slew capability Acceleration: 0.1"/sec^2

* Model Scale may be varied slightly if required, to accommodate other limits and tolerances.

of providing earth horizon keying signals in the sensing and processing optical and cctv systems. The upper surfaces of the mask shall also be decorated so as to provide horizon imagery for summing with high and low altitude model video signals. The exposed surface of the model shall be uniformly and diffusely illuminated to a level of 1500 foot-candles minimum.

5.2.1.2 High Altitude Earth

The high altitude earth model shall provide the means of simulating the transition between orbital earth scenes and high altitude operations such as re-entry, energy dissipation, and final approach alignment. It shall consist of a two-dimensional representation of a 1000 nm x 1000 nm terrain area scaled at 7.34×10^5:1. The model center shall be coincident with a high resolution area at the location of the Kennedy Space Center Facilities (KSC), Florida. All of the major topographical features in designated land/sea areas shall be accurately depicted. Terrain and sea hues, and hue variation shall be reproduced. Maximum attention shall be given to the clear reproduction of demarkations between terrain features, seas and rivers. Visually distinct demarkations between natural topological features within landmass areas shall be depicted. Maximum scene detail shall be provided at the map center in the immediate vicinity of the KSC facilities area. Use shall be made of aerial photographic data to provide accurate and high resolution detail within a radius of 25 miles of the KSC facilities, supplemented manually with additions to the facilities specific to Shuttle Mission operations. Detail rendering in the high resolution area shall be 200 feet or less, and 1,500 feet in outlying areas.

The map model board shall be designed for rigid vertical mounting, shall be readily mounted and demounted without undue difficulty or risk of damage to other components of the system. A camera transport mechanism capable of providing translational freedoms and dynamics as specified in table 5.2 shall be provided. The model illumination system shall be capable of providing uniform diffuse illuminance levels to a maximum of 1,500 foot-candles.

5.2.1.3 Orbital, High Altitude Clouds, Ascent Sky, Terminator

Cloud cover for the orbital and high altitude scenes shall be generated by a closed circuit television system sensing projected imagery. The video signals shall be provided in a form suited to keying and mixing with earth and high altitude video channels. An ascent sky and earth terminator image source shall also be provided

TABLE 5.2

HIGH ALTITUDE EARTH MODEL LIMITS & TOLERANCES

Item	Requirement
Model Scale*	$7.35 \times 10^5:1$
Model Size	8' x 8'
Model Board Surface Flatness	$\pm$ 0.03" over total visible area
Camera Transport Mechanism	Excursions: 14 feet lateral (X) 14 feet longitudinal (Y) 4 feet vertical (Z) Velocities: $\dot{X}$: $\pm$ 0.15 inches/sec $\dot{Y}$: $\pm$ 0.15 inches/sec $\dot{Z}$: $\pm$ 0.03 inches/sec Accelerations: $\ddot{X}$: $\pm$ 0.001"/sec^2 $\ddot{Y}$: $\pm$ 0.001"/sec^2 $\ddot{Z}$: $\pm$ 0.001"/sec^2
Position Repeatability	$\pm$ 0.02" error maximum to combined X-Y-Z commanded location.

* Model Scale may be varied slightly to accommodate other limits and tolerances.

by this equipment group. The equipment shall take the form of a projection system which forms diffuse images on the inside surface of a 6 foot radius, spherically curved translucent screen with a cap diameter of 6 feet. Three individual high intensity projectors and associated film cassettes and transport mechanisms shall generate orbital earth, high altitude and ascent sky cloud scenes, during applicable mission phases. The film formats, projection light sources and projection lens apertures shall be chosen such that individual film frames are subjected to illumination levels of less than 1,000 lumens per square centimeter. Film temperature shall be less than 160°F during indefinite stationary exposure to the projector light sources.

The orbital earth cloud cover projected image format shall fill the inside screen surface area. Sufficient film shall be provided to generate realistic, recognizable cloud formations non-repetitively over a minimum period of 90 minutes. The film drive mechanism shall provide a single degree of image translation freedom at the analog of orbital rate. The high altitude cloud cover projector shall illuminate the center zone of the projection screen, project a circular format image 24 inches in diameter at the center of the screen. Cloud patterns shall be provided corresponding to recognizable formations as viewed vertically in the altitude range 1.2×10^5 feet to 5.2×10^4 feet. The film transport mechanism shall provide a single degree of translational freedom with a speed corresponding to the scaled range of the high altitude translational velocity vector.

The ascent/sky cloud projector shall illuminate the total inside surface of the screen with a static cloud/sky image consisting of recognizable cloud formations against a blue sky background. The center of the image shall correspond to a vertical line-of-sight view. A terminator mechanism shall be provided consisting of a curved shield with graded translucency positionable in azimuth and elevation internally to the projection screen. The terminator shield shall occult the orbital earth cloud cover scene imagery to produce a realistic day/night transition zone during appropriate orbital conditions.

A keying mask shall be positioned over, and in close proximity with the outside surface of the projection screen, enclosing the screen cap diameter of 6 feet. The keying mask shall be decorated with light absorbent materials in order that luminance differences between the screen surface and mask may be used to generate video keying signals. Upper surfaces of the mask shall also be decorated to provide appropriate horizon effects for the low altitude model. Each projector shall be capable of producing a screen surface illuminance of 1,500 foot-candles minimum, open-gate operation.

5.2.1.4 Low Altitude

The low altitude model shall consist of a three-dimensional scaled representation of a sea/terrain area of 20 nm x 20 nm centered at the KSC facilities. The model shall be scaled at 3,061:1. All of the principal cultural and topological features of the area external to the Shuttle operational facilities at KSC shall be accurately reproduced in appropriate hues. Maximum emphasis shall be placed on detail rendering within a circular area of five miles centered at the location of the runway designated for Shuttle landing and take-off operations.

All of the principal landmark features of the KSC facility shall be modelled, incluing the Vertical Assembly Building, launch facilities, access roads and principal services buildings. The orbiter landing facilities shall be accurately rendered, including a runway 10,000 ft. by 150 ft., fully equipped with all weather markings, ILS day and night operations visual aids. Night landing aids shall include 3,000-foot approach lighting at both runway ends, approach strobe, threshold and center line lighting, appropriate touchdown zone lighting and runway end identification lights. A visual glide slope indicator system, specific to orbiter initial approach glide slope, shall be included. The general appearance of the runway, associated service roads, maintenance buildings, and control tower shall conform to those specific to Shuttle operations. For the purposes of simulating night operations, highway lighting, and the lighting patterns characteristic of the immediate landing area shall be reproduced.

Detail reproduction in the model may be varied from the edges to the center with maximum attention being paid to detail at the center of the model, and in particular to the rendering of the landing strip and markings. In outlying model regions, only terrain and cultural features in appropriate hues need to be reproduced. Demarkation between different topological areas shall, however, be sharply reproduced, where appropriate. In the immediate runway area, accurate demarkation between high contrast features (e.g., white centerline stripes, 500-foot strip markers and runway center line markings) shall be reproduced by providing transitions between model pigments with edge sharpness of .002" or less. Artifacts in the immediate runway area with dimensions of greater than 6 feet (ILS instrumentation huts, blast shields) which provide height and distance cues during VFR approach and landing shall be appropriately modelled.

The model shall be designed for vertical mounting and shall be of modular construction. The center section of the model containing the runway associated landing aids and facilities shall be easily removable to enable model update and replacement.

A camera transport mechanism shall be provided for the purposes of positioning the model camera system within the tolerances and limits specified in table 5.3. The transport mechanism shall be supported along the upper horizontal extremity of the model in such a manner as to minimize sway and vibration, and to maintain positioning and repeatability tolerances as specified in table 5.3. Controllable diffuse model illumination for the purposes of day/night lighting conditions shall be provided. Model maximum illumination shall be not less than 1,500 foot-candles.

5.2.1.5 Rendezvous, Payload Docking Targets, Aft Orbiter Body, Star Field

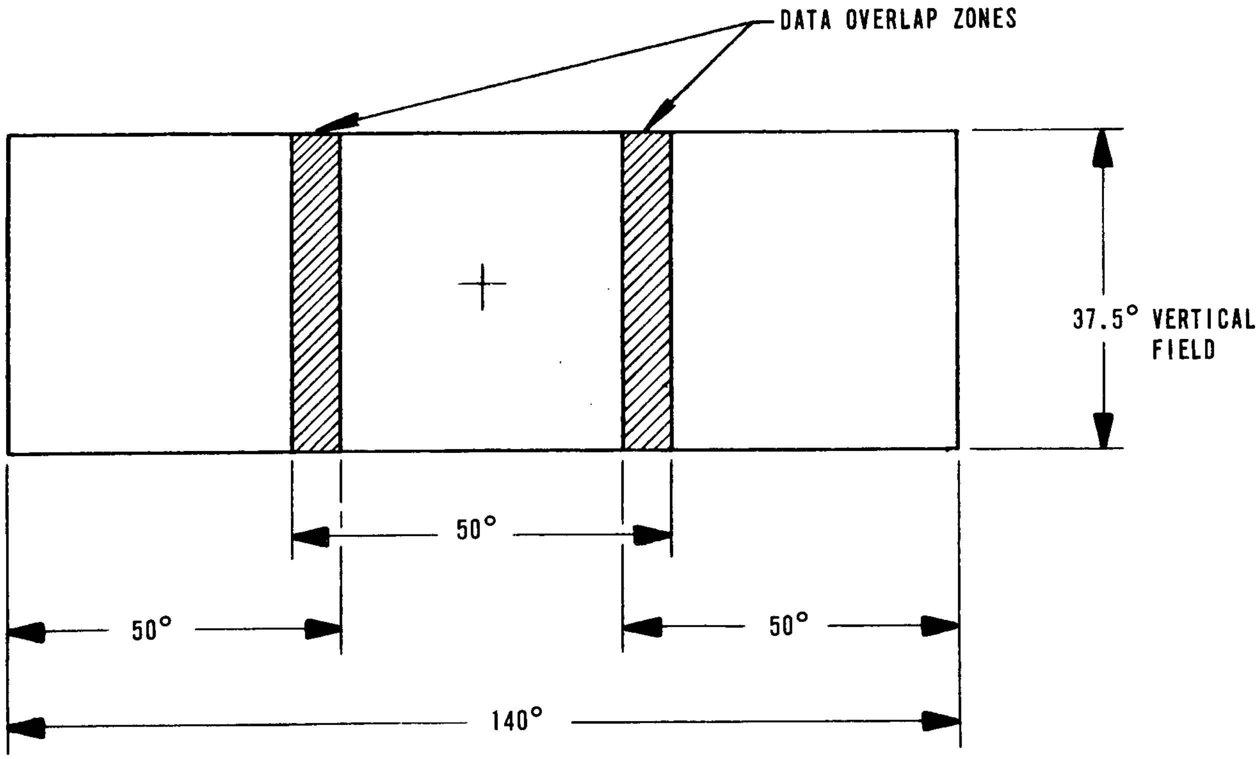
Rendezvous, payload, docking targets, and aft Orbiter body including Remote Manipulator System (RMS) and star field shall be generated by computed image techniques. A total of four channels of data shall be provided, three for external visual displays, and a fourth for the simulation of the RMS wrist element closed circuit television system. The fourth channel computations shall also provide a signal at the event of arm/payload contact for the initiation of force feedback simulation during combined arm and payload mass motion. The field-of-view formats for the external visual displays and RMS closed circuit system shall be as shown in figure 5.1. The channel image computations shall be compatible with a raster format of 1,248 active scan lines at 60 fields per second with 2:1 interlace. The computed image resolution element size shall be equal in vertical and horizontal directions, and be such that a pattern with a spatial frequency of 450 vertical

TABLE 5.3

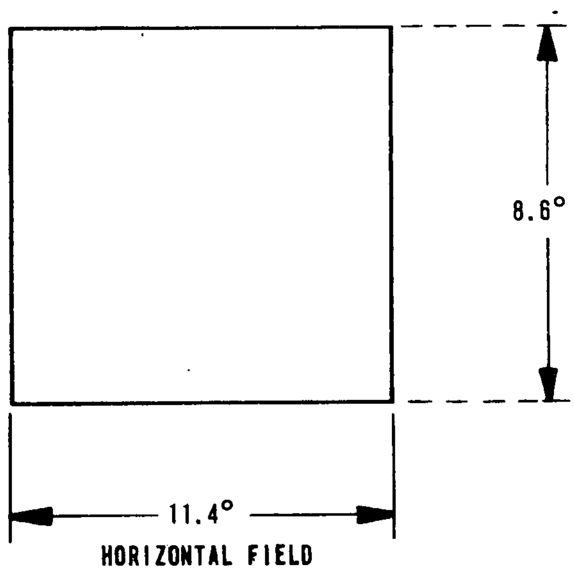
LOW ALTITUDE MODEL LIMITS AND TOLERANCES

Item	Requirement
Model Scale*	3060:1
Model Size:	41' X 41'
Model Surface Flatness:	0.15" overall, with 0.03" flatness within a surface area of 4 feet by 4 feet, about the center of the runway.
Camera Transport Mechanism:	Excursion Envelope: height (X) 45 ft. width (Y) 45 ft. depth (Z) 6 ft.
	Positioning Accuracy: X $\pm$ 0.09" Y $\pm$ 0.09" Z $\pm$ 0.030"
	Velocity: $\dot{X}$ o $\pm$ 3"/sec $\dot{Y}$ o $\pm$ 3"/sec $\dot{Z}$ o to $\pm$ 1.5"/sec
	Acceleration: $\ddot{X}$ o to $\pm$ 0.2" sec^2 $\ddot{Y}$ o to $\pm$ 0.2" sec^2 $\ddot{Z}$ o to $\pm$ 0.3" sec^2

*Model Scale may be varied slightly if required, to accommodate other limits and tolerances.



TOTAL HORIZONTAL FIELD EXTERNAL DISPLAYS CHANNEL



HORIZONTAL FIELD

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RMS CCTV FORMAT

FIGURE 5.1 PROBE IMAGE FORMAT

line pairs shall be resolved at the external display kinescopes, with a contrast ratio of 60% or more. At least ten distinguishable grey scales, and ten distinguishable hues selectable from combinations of the primary colors shall be provided under software control, for the purposes of providing color scenes in the external displays. The simulated RMS display format shall be monochrome, with a raster format of 525 lines at 60 fields, 2:1 interlace with an aspect ratio of 4:3. The resolution element size shall be equal in vertical and horizontal directions and such that a pattern with a spatial frequency of 200 vertical lines shall be resolved with a contrast ratio of 20% or better. Ten distinguishable grey scales shall be provided.

The external displays channels shall be assignable to either forward or aft displays depending upon mission phase and training requirements. In the case of active forward displays, the field of view shall be referenced to an effective eyepoint midway between commander and pilot nominal eyepoint, and disposed in response to control signals as follows:

a. Symmetrically about the vehicle center line
b. 50^{o} Inboard (pilot quarter and side window display)
c. 50^{o} Outboard (commander quarter and side window display)

With the forward displays inactive and aft displays in operation, two reference eyepoints, and two field-of-view orientations shall be selectable, one corresponding to overhead RMS operations, the other to direct aft RMS operations. Selection of the eyepoint and its corresponding field orientation shall be determined by seat position changes during payload manipulation operations. The computed image data channel associated with RMS wrist mechanism cctv simulation shall be assignable to a look-point corresponding to either right or left arm operation.

A minimum processing capability of 2,250 real-time edges within the four data channels shall be provided. Of these, 1,000 edges shall be assigned to the simulation of the aft orbiter body, open cargo bay doors, cargo bay interior and RMS arm mechanism. Data base granularity shall be 1/64-inch or less. The remaining edges shall be assigned to the simulation of any one of the population of Rendezvous, Docking and Payload objects listed in table 5.4. Keying signals shall be generated in addition to shape data to permit the insetting of rendezvous targets into the forward field against earth scene and star field scenes. Edge smoothing shall be implemented in image processing in order to reduce the visual effects of object-edge interaction with individual raster lines. Shading shall be implemented where necessary to improve the realism of curved surface simulation, and sun angle illumination.

The dynamics of either left or right RMS arm mechanism interaction with the targets listed in table 5.4 shall be simulated. For the purposes of simulation, the orbiter vehicle attitude shall be considered stable during RMS operations. The simulation dynamics of arm elements, arm-tip motion and wrist angular freedoms shall conform to those listed in table 5.5. Target objects shall be capable of at least one continuous degree of rotational freedom prior to capture, about an approximate mass center, in the angular range 0-5^{o} per second.

A data base consisting of 1,000 point images shall be provided for the purpose of star field simulation. The point images shall be designated by angular coordinates in the CGI equipment host processor corresponding to the locations of stars in the major constellations. Point intensity shall be controlled over a range of 64:1 as a means of simulating stellar magnitude in the range -1 to +5. The star field simulation shall be provided in either the forward or aft displays in accordance with mission phase.

5.2.2 Image Sensing and Processing

5.2.2.1 Image Sensing

A wide-angle three-channel segmented field optical probe shall be the basic sensing device in the orbital Earth, High and Low altitude, and Cloud Scene image generation equipment. The probe image format, channel coverage and overlap are shown in figure 5.1 and shall be common to all probes. The field

TABLE 5.4

PAYLOAD AND DOCKING TARGETS

Device	Principal Characteristics & Dimensions
Habitable Module	Cylindrical, 15' diameter by 14' 9" length, equipped with viewports, access tunnel and hatch.
Orbit-to-Orbit Shuttle (OSS)	Cylindrical with engine nozzle. Overall length 35.2 feet, diameter 15 feet.
Intelsat IV	Cylindrical, 103 inches diameter, 111 inches length, with attached spheres.
DI-T Centaur Modified for Shuttle Operations	Cylindrical, overall length 32', diameter 10'. Engine and engine nozzle clearly visible aft.
TIROS Surveillance Satellite	Complex cube approximately 40" side, 3 deployable solar panels. Externally visible subsystems include S band antenna, scanning radiometer, momentum flywheel and TV camera optics.
MSS Core Module	Cylindrical with truncated conical docking ports. Overall length 41' 6", overall diameter, 12'. Multiple passive docking ports distributed over outer surface.
Partially Assembled MSS	Core module with one or more applications modules attached. Applications module to be selected from a family of 7 cylindrical devices, diameters 14 feet, overall lengths varying from 18.3 to 68.5 feet. External subsystems include solar cell arrays, docking drogues and probes; deployable EVA inspection hatches.

TABLE 5.4 (Cont)

Device	Principal Characteristics & Dimensions
Orbiter Vehicle	Characteristics as for baseline orbiter vehicle.
Detached Application Modules	Family of 7 cylindrical devices, diameter 14 feet, lengths varying from 30 to 33 feet. Externally visible components as for attached AM's.

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TABLE 5.5
RMS MANIPULATOR ARM DYNAMICS

PARAMETER \ ITEM	SHOULDER PITCH	SHOULDER YAW	ELBOW ROLL	ELBOW YAW	WRIST ROLL	WRIST PITCH	WRIST YAW	TIP TRANSLATION
ANGULAR RANGE	±200°	±130°	±200°	±155°	±200°	±120°	±120°	
NO LOAD RATE/VELOCITY	0.03 R/S	0.03 R/S	0.057 R/S	0.057 R/S	0.175 R/S	0.175 R/S	0.175 R/S	1.5 FT/S
NO LOAD ACCELERATION	0.015 R/S^2	0.015 R/S^2	0.028 R/S^2	0.028 R/S^2	0.087 R/S^2	0.087 R/s^2	0.087 R/S^2	0.75 FT/S^2
FULL LOAD RATE/VELOCITY	3.5×10^{-3} R/S	3.5×10^{-3} R/S	6.6×10^{-3} R/S	6.6×10^{-3} R/S	2.65×10^{-2} R/S	2.65×10^{-2} R/S	2.65×10^{-2} R/S	0.174 FT/S
FULL LOAD ACCELERATION	8.87×10^{-4} R/S^2	8.87×10^{-4} R/S^2	1.75×10^{-3} R/S^2	1.75×10^{-3} R/S^2	2.32×10^{-3} R/S^2	2.32×10^{-3} R/S^2	2.23×10^{-3} R/S^2	.0018 FT/S^2

segment minimum resolving power for each probe for an axially-viewed high-contrast square wave target shall be as follows:

a. Center segment: 100 line pairs per millimeter at 40% contrast ratio.
b. Edge segments: 75 line pairs per millimeter at 40% contrast ratio.

The overall probe effective aperture (t-number), including field-splitting optical components, shall not be more than 125. Angular freedoms shall be implemented by optical means in accordance with the values shown in table 5.6.

5.2.2.2 Closed Circuit TV System

The closed circuit television system shall process, route and switch the video signals derived from the system image generation equipment. Three video channels per image generation equipment group shall be provided. In the case of model and film image generation, three-channel isocon camera systems shall be employed and provisions shall be made for processing of synthetic video signals derived from the computed image generation equipment.

The visual system closed circuit television equipment shall consist of the following elements:

a. Isocon Camera Units
b. Camera Control Units
c. Master Synchronizer
d. Camera Switching
e. Video Keying
f. Processing System
g. Displays Switcher.

5.2.2.2.1 Isocon Camera Units

Each of the five optical probes shall be interfaced with a three-channel camera system consisting of isocon pick-up tubes, video signal preamplifiers and deflection magnetics. The video preamplifiers gain, bandwidth and noise performance shall be considered as an element of the TV keying and Video Processing System,

TABLE 5.6

PROBE ANGULAR PERFORMANCE REQUIREMENTS

	ANGULAR EXCURSION			ANGULAR RATES (MAXIMUM)			ANGULAR ACCELERATION (MAXIMUM)		
	ϕ	θ	ψ	$\dot{\phi}$	$\dot{\theta}$	$\dot{\psi}$	$\ddot{\phi}$	$\ddot{\theta}$	$\ddot{\psi}$
ORBITAL EARTH	CONT	$+60^\circ$ TO -120°	CONT	12°/SEC	1.5°/SEC	10.5°/SEC	$8.25^\circ/SEC^2$	$4.6^\circ/SEC^2$	$5.35^\circ/SEC^2$
CLOUD COVER MODEL	CONT	$+60^\circ$ TO -120°	CONT	30°/SEC	10°/SEC	10°/SEC	$85^\circ/SEC^2$	$30^\circ/SEC^2$	$40^\circ/SEC^2$
HIGH ALTITUDE MODEL	CONT	$+60^\circ$ TO -120°	CONT	30° SEC	10° SEC	10°/SEC	$85^\circ/SEC^2$	$30^\circ/SEC^2$	$40^\circ/SEC^2$
LOW ALTITUDE MODEL	CONT	$+60^\circ$ TO -120°	CONT	30°/SEC	10°/SEC	10°/SEC	85° SEC^2	$30^\circ/SEC^2$	$40^\circ/SEC^2$

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the requirements for which are stated in paragraph 5.2.2.2.7. Each isocon pick-up tube shall be provided with a pair of spatial frequency color encoding filters. The filter pair shall consist of red and blue stop gratings, crossed at an angle of 49° and having a stripe density of 820 stripes per inch.

5.2.2.2.2 Camera Control Units

Each isocon pick-up tube shall be provided with a remotely mounted camera control unit. Individual camera units shall control isocon beam current, beam acceleration, target potential, dynode gain, focus and deflection signals and adjustments. Horizontal and vertical sweep and sweep blanking signals shall also be provided. Video output signal processing shall include aperture correction, shading compensation, sync addition, keyed clamping and luminance peak clipping. The camera control unit shall extracc chrominance data from the camera video signals by detecting and demodulating the frequencies derived from the red and blue stop optical filters at the pick-up tubes. A matrix decoding circuit shall be provided in each channel for synthesizing green hues from the red, blue and luminance video signals. The bandwidth of the green signal so derived shall not be less than 2.5 MHz. Gain controls, color correction and compensation adjustments shall be provided for accurate color setup.

5.2.2.2.3 Master Sync Unit

A Master Synchronizing signal generator conforming to EIA standards shall be used to synchronize all camera sweep and blanking signals, and to provide the controlling display frame timing signals in the Computed Image Equipment. The synchronizing signal repetition shall be that required to generate a raster format of 30 frames per second, 1,248 active scan lines with 2:1 interlace.

Blanking times shall be 4.4 ± 1 us for horizontal and 1,250 ± 1 us for vertical retrace.

5.2.2.2.4 Camera Switching

The continuity of scenes during all mission phases shall be controlled by a camera switching matrix. The camera switching matrix shall accept scene transition commands and switch appropriate video luminance and chrominance channel groups to the

Keying and Video Processing System. In a typical nominal launch switching sequence, ascent/sky, high altitude and high altitude cloud cover, orbital earth and orbital earth cloud cover video channel groups shall be input to the Keying and Video Processing System. The camera switching matrix shall also control all other sequences requiring transitions between scene element image generation equipment, both in nominal mission, and abort situations. Switching commands shall be accepted from both the mission simulator computer and from maintenance equipment, and shall be implemented during the system vertical blanking interval.

5.2.2.2.5 TV Keying and Video Processing Systems

The TV Keying and Video Processing System shall combine the scene element video signals in such a manner that a realistic composite scene is produced. The video input channel groups are defined as follows:

a. Earth Video: Three video channels originating from either the orbital earth, high altitude or low altitude models.

b. Cloud Video: Three video channels originating from the cloud scene image generation equipment corresponding to ascent/sky, orbital earth, high altitude earth and low altitude horizon images.

c. Aft Orbiter; RMS and Target Object Video: Synthetic video originating from the computed image equipment.

d. Star Field Video: Point source signals originating from the computed image generation equipment.

A priority keying scheme shall be implemented which appropriately insets the target or aft scene elements into the earth scene and/or star field and also insets the earth video into the star field. Detection for keying shall be determined by luminance level.

The cloud video luminance signal shall be used for the control of cloud luminance level, and for deriving earth attenuation control in response to earth terminator-shading and cloud density.

During the time the video representing cloud luminance is present, it shall be summed with the attenuated earth video in such a manner that appropriate earth detail will be visible through light density clouds in the final display. For high altitude and terminal area scenes, the cloud video shall be used for summing into the composite scene cloud/sky information above the horizon and/or low visibility effects obtained from the cloud/sky/terminator source. A synthetically-generated fog source shall also be provided for simulating visual effects of clouds of variable density in the low altitude earth scene. This signal shall be summed with earth video with cloud gain level and earth attenuation level controlled by programmed or operator-controlled analog signals.

When luminance video signals are switched by the keying signals, the associated chrominance signals shall also be switched. Delay compensation shall be provided to match delays between signals for the composite scene.

Provisions for adjustment of keying thresholds, video gain levels, attenuation control functions, restored black reference levels, and other necessary parameters shall be provided to allow the alignment for achieving a realistic and accurate composite scene. Test points shall be provided which are easily accessible for monitoring critical signals such as input video, earth attenuation, keying logic levels, restored video prior to summation, and composite scene video. Buffered composite scene video shall also be available for a TV display monitor in the Maintenance Control and Test Station.

5.2.2.2.6 Display Switcher

The Display Switcher shall route the composite scene video signals to the appropriate displays forward and aft field equipment. In the forward field, four of six display units shall be active at any one time with the two forward windows displaying identical information. Video signals shall therefore be switchable to the forward display units depending upon training priorities, as follows:

a. Left segment video to left quarter window, center segment video to forward windows, right segment video to right quarter window.

b. Left segment video to left side window, center segment video to left quarter window, right segment video to forward windows.

c. Left segment video to forward windows, center segment video to right quarter window, right segment video to right side window.

The inactive forward view display units and the aft display units shall be blanked. In the case of active aft display, the composite scene video shall be switched to the three aft display units and the forward displays shall be blanked. The switching commands shall be discrete computer output signals with provisions for overriding by switch commands from the Maintenance Control and Test Station.

Any one of the three video channels shall also be selectable at the Operator Station to be routed to a separate output of the Display Switcher for the purposes of channel-monitoring.

5.2.2.2.7 Closed Circuit TV System General Requirements

The individual video channel performance characteristics, including video preamplification, processing and switching shall be as follows:

VIDEO BANDWIDTH	
Luminance Video	23 MHz $\pm$ 3 db
Chrominance Video	2.5 MHz $\pm$ 3 db
SIGNAL-TO-NOISE RATIO	30 db
CROSS TALK (between inputs or outputs to inputs)	40 db
VIDEO INPUT IMPEDANCE	75 Ω
VIDEO OUTPUT IMPEDANCE	75 Ω
SWITCHER TRANSITION TIME (within vertical interval timing)	1 μs
SWITCHER DIFFERENTIAL GAIN	1%

KEYING SWITCHING TIME	
Luminance Video	22 ns
Chrominance Video	100 ns
KEYING ERRORS	0.01%
RASTER FORMAT	
Frame Rate	30 frames/sec
Scan Rate	1,248 active lines/frame 1,357 effective lines/frame
Interlace	2:1
Horizontal Blanking Period	4.4 ± 1 μs
Vertical Blanking Period	$1,250 \pm 100$ μs

5.2.2.3 Displays Subsystems

Non-pupil-forming virtual image displays shall be provided for viewing mission scenes from the Vehicle Commander, Pilot and Payload Handling Station design eyepoints.

The display equipment shall be modular in construction, each module consisting of a spherical mirror with image-folding beamsplitter and large format color display cathode ray tube. The display modules shall be configured so as to permit edge registration and shall provide a wide, continuous field in the forward field horizontal direction, and a wide field in the vertical direction at the payload handling station eyepoints. Individual modules shall provide a total field of view of 50° by 37.5°, and an instantaneous field of view of 45° by 28° with the eyepoint located at the center of mirror curvature. No portions of the displays equipment or displays support structure shall intrude into the cockpit or payload station internal structure. The display modules shall be rigidly constructed so as to withstand the motion system nominal and malfunction acceleration envelope. Maximum weight per module, including displays electronics, shall not exceed 300 lbs.

5.2.2.3.1 Forward Field Displays Equipment

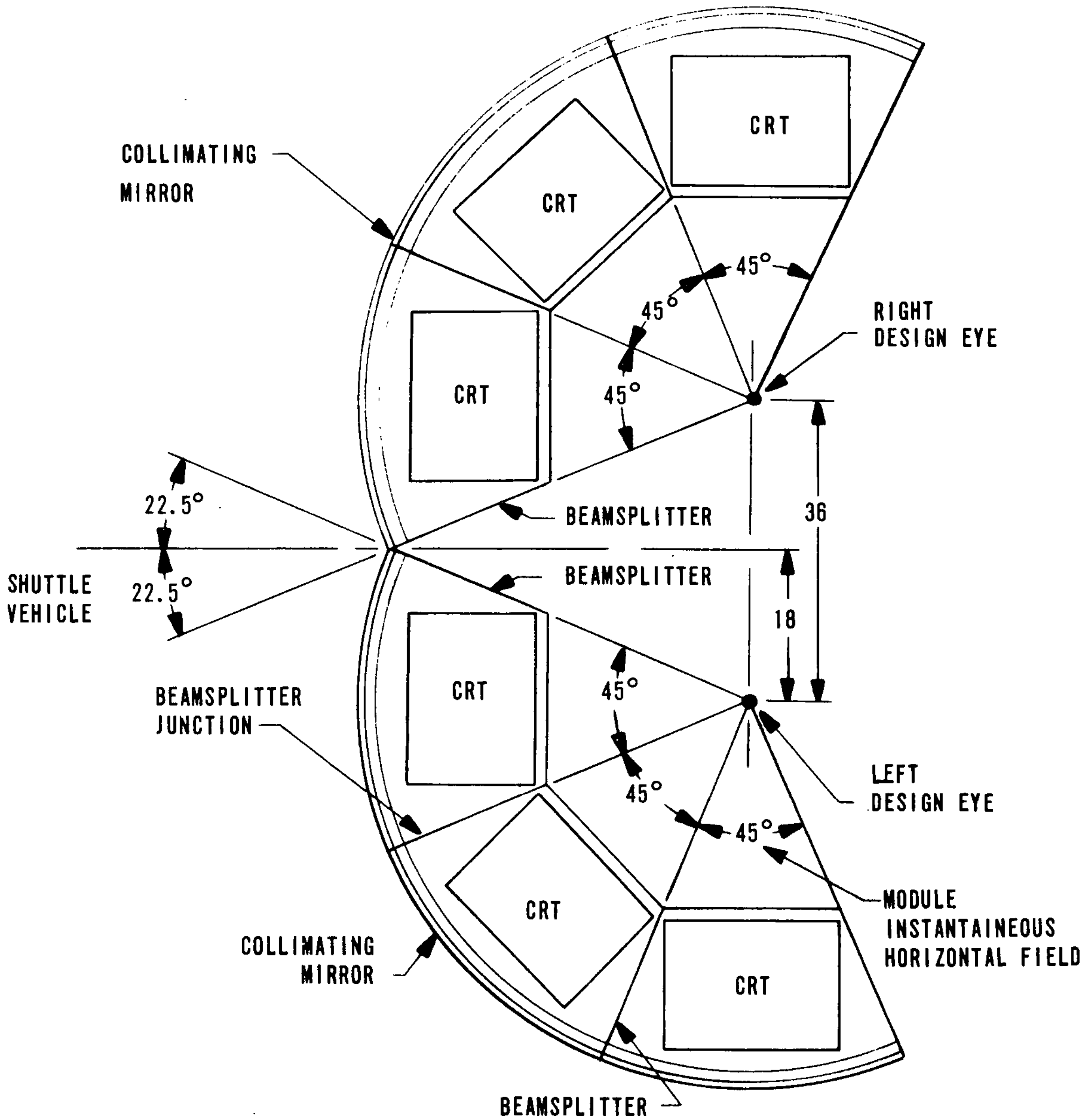
The forward field displays configuration shall consist of six modules arranged in groups of three to provide independent fields of view from the left and right vehicle design eyepoints. Eyepoint separation, eye relief, and field orientation shall be as shown in figure 5.2. The total instantaneous field from each eyepoint shall be continuous when observed at the common center of curvature. Beam-splitter seam and edge effects shall be minimized by accurately mating adjacent beam-splitter edges. Scene discontinuities due to residual mating effects shall not exceed 1° when viewed from the left and right design eyepoints. All regions of the left and right field virtual image shall appear to be no closer than 60 feet from the observer. Image displacement (parallax) due to head motion shall be in the correct direction as the eyepoint is moved laterally over distances of ± 6 inches from the design eyepoint. The effects of zonal differences in image magnification, if any, shall be considered as a factor contributing to geometric distortion (table 5.7) in the integrated optics/display device operation.

5.2.2.3.2 Aft Field Displays Equipment

The aft field displays equipment shall consist of a group of three display modules of identical design to those specified for the forward field. A two-degree of freedom displays transport mechanism shall be provided to translate and rotate the displays group, on command, from an aft eyepoint A (overhead RMS operations) to an eyepoint B (aft RMS operations). The general displays arrangement shall be as shown in figure 5.3. In order to accommodate the payload handling station structure, the displays group common center of curvature may be displaced vertically from eyepoint A, by a maximum of 6 inches.

5.2.2.3.3 General Perceptibility Requirements

The forward and aft field displays subsystems when integrated with the closed circuit television system shall meet the perceptibility requirements listed in table 5.7.



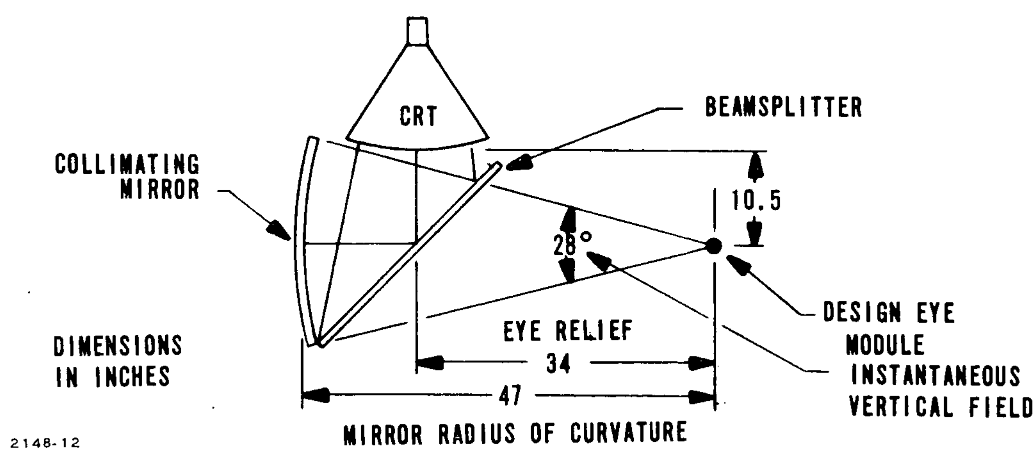


FIGURE 5.2 FORWARD FIELD DISPLAYS EQUIPMENT

TABLE 5.7

GENERAL PERCEPTIBILITY REQUIREMENTS

Item	Requirement
Displayed Image Luminance:	15 foot lamberts peak highlight 10 foot lamberts average highlights
Displayed Image Limiting Resolution:	(a) Luminance: 6 arc minutes at 50% contrast ratio (square wave high contrast target) (b) Chrominance: 1° at 50% MTF over available hue range
Luminance Range:	Ten distinguishable black and white scales.
Contrast:	50:1 with background environmental luminance .01 foot candles.
Geometric Distortion:	Combined optics and display cathode ray tube distortion less than $\pm$ 2% in individual modules, and $\pm$ 2% maximum over full field.
Permissible Head Motion:	All perceptibility requirements with the exception of field continuity shall apply for head motion within a sphere of 6-inch radius centered at design eyepoints.

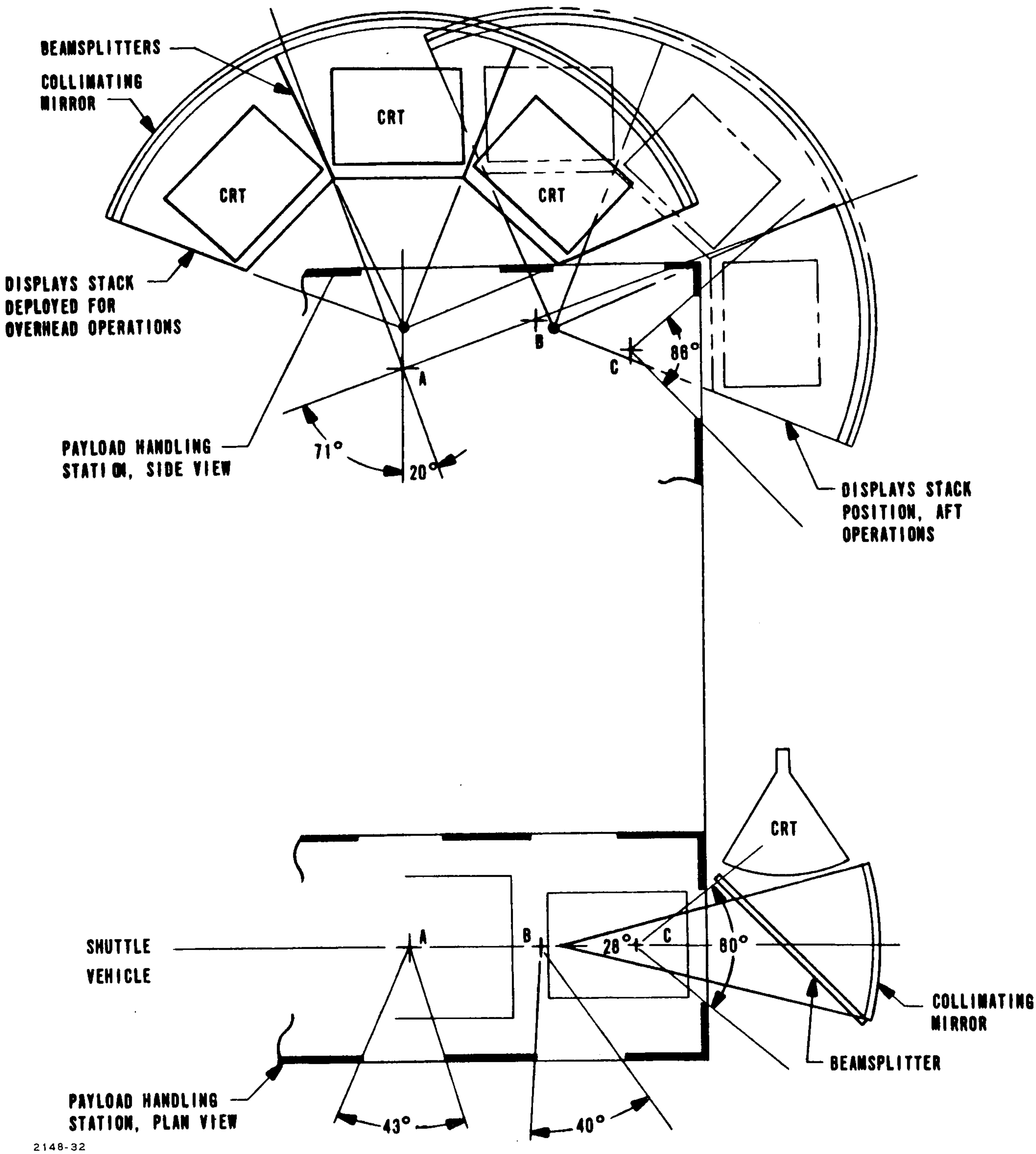


FIGURE 5.3 AFT DISPLAYS CONFIGURATION

6.0 COST ANALYSIS

Cost estimates for the Baseline System are presented in tables 6.1 and 6.2. Table 6.1 contains the estimates for the component costs, and table 6.2 contains estimates of costs associated with overall program activity, facilities, and systems integration.

In arriving at estimates, the following assumptions were made:

a. A system procurement and installation schedule of 30 months from go-ahead to on-site system acceptance, with the facility ready for the installation of the first major items (high and low altitude models) by the end of month 19.

b. All major subcontract items delivered directly to site after acceptance testing at the subcontractor facilities.

c. Major structural facility modifications and additions such as floors, ceilings, fire protection, utility power, plumbing, etc., provided by the procuring agency.

d. Systems integration initiated on-site beginning at month 18, and continuing until final acceptance completion (month 30).

In arriving at table 6.1 estimates, purchased parts are defined to include subcontract items, and items purchased off-the-shelf are either used directly, or modified for some specific application. The estimates are for equipment manufactured in accordance with commercial standards. It should be noted that the application of military specification design standards and documentation to purchased and subcontract items could significantly increase the estimates. In the apportioned costs, engineering estimates include such activities as design, drafting, technical liaison with subcontractors, preparation of test procedures, acceptance testing, and coordination with manufacturing activities. Product support, which was estimated on a commercial basis, includes the preparation of technical manuals, spares provisioning and some reliability, quality and standards services.

TABLE 6.1
SYSTEM COMPONENTS COSTS

BASELINE SYSTEM COST ESTIMATES

	ITEM	COST (DOLLARS)	SUBTOTAL	SUBTOTAL
IMAGE GENERATION EQUIPMENT	LOW ALTITUDE MODEL		603,000	4,247,000
	PURCHASED PARTS: MAP MODEL, TRANSPORT MECHANISM, ILLUMINATION SYSTEM	400,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	203,000		
	HIGH ALTITUDE MODEL		387,000	
	PURCHASED PARTS: MAP MODEL, TRANSPORT MECHANISM, ILLUMINATION SYSTEM	245,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	142,000		
	ORBITAL EARTH MODELS		808,000	
	PURCHASED PARTS: SPHERES, DRIVES, TRANSPORT MECHANISMS	404,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	204,000		
	SKY CLOUD PACKAGE		243,000	
	PURCHASED PARTS: SCREEN, PROJECTION COMPONENTS, TERMINATOR MASK UNIT, TRANSPORT MECHANISMS, PHOTOGRAPHIC SERVICES	101,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	142,000		
	COMPUTED IMAGE SYSTEM		2,206,000	
	PURCHASED PARTS: 32 BIT MEDIUM SCALE COMPUTER 16 K CORE, MULTIPLEX I/O PROCESSOR, FP HARDWARE	254,000		
	PERIPHERAL EQUIPMENT (DISK, PAPER TAPE, TTY)	52,000		
	4-CHANNEL CGI EQUIPMENT	1,250,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	650,000		
IMAGE SENSING AND PROCESSING EQUIPMENT	OPTICAL PROBES:		814,000	1,854,000
	PURCHASED PARTS: 5-3 CHANNEL UNITS	575,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	239,000		
	CLOSED CIRCUIT TV SYSTEM		1,040,000	
	PURCHASED PARTS: CAMERAS, CAMERA CONTROL UNITS, KEYING EQUIPMENT, VIDEO PROCESSING ELECTRONICS	450,000		
	APPORTIONED COSTS: ENGINEERING DEVELOPMENT, PRODUCT SUPPORT, G/A, FEE	590,000		
IMAGE DISPLAYS	DISPLAY OPTICS:		189,000	368,000
	PURCHASED PARTS: MIRRORS, BEAMSPLITTERS (9 UNITS), STRUCTRUAL COMPONENTS	62,000		
	APPORTIONED COSTS: ENGINEERING, PRODUCT SUPPORT, G/A, FEE	127,000		
	DISPLAY DEVICES:		179,000	
	PURCHASED PARTS: KINESCOPES, DISPLAYS ELECTRONICS, MAGNETICS	57,000		
	APPORTIONED COSTS: ENGINEERING DEVELOPMENT, PRODUCT SUPPORT, G/A, FEE	122,000		
			SYSTEM TOTAL ESTIMATED COST:	6,469,000

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TABLE 6.2
PROGRAM COST ESTIMATES

ITEM	COST (DOLLARS)
FACILITY REQUIREMENTS AIRCONDITIONING INSTALLATION ELECTRICAL POWER CONTROL, PROTECTION AND DISTRIBUTION	125,000
PROGRAM TECHNICAL SUPERVISION	575,000
INTERFACE SYSTEMS ENGINEERING	467,000
SYSTEM INTEGRATION	340,000
TOTAL:	1,507,000
SYSTEM COMPONENTS COSTS TOTAL:	6,469,000
TOTAL ESTIMATED COSTS	7,976,000

As in the case of purchased parts, the imposition of more rigid quality control, reliability and maintainability programs would significantly increase the overall apportioned costs estimates. Certain items in the cctv system are expected to require development activity to advance the state-of-the-art in image processing. Specifically, the development of spatial frequency encoding and decoding techniques is a requirement for generating color scenes. The estimated cost of a development program has been included in the relevant table entry.

The CGI data base processor cost is based on catalog price information on a 32-bit machine with floating-point hardware, two-level priority interrupt, and multiplexed I/O processor. Peripheral equipment estimates are for a 7M byte disk unit, 300 lpm line printer, keyboard/printer, 300 cpm card reader and paper tape equipment. It is anticipated that the cost is fairly representative of a machine employed as the data base computer in the CGI system.

The figures presented in table 6.2 are anticipated overall program costs, including interface systems engineering, systems integration, and technical supervision. Facility requirements estimates are for air conditioning and electrical power control. The preparation of the facility for equipment installation is not included. The estimate for interface systems engineering includes the following activity:

a. Visual System/Mission Simulator hardware and software interface design and coordination.

b. Visual Systems/Facility interface design and coordination.

The program technical supervision estimate provides for first-level program control, and second-level supervision in areas such as electro-optics, servo system design, video system engineering and mechanical engineering.

Systems integration includes pre and post-equipment installation activity. In the case of major subcontract items, the purchased parts estimates include (table 6.1) costs for subcontractor participation in equipment installation and preparation for final acceptance testing. The systems integration activity is assumed to take place over a period of thirteen months commencing at month 18, peaking at month 21, and remaining at peak level through month 30.

The total estimated system cost is based on current equipment costs, overhead, fee, and administrative charges. An appropriate economic factor should be included in arriving at the system cost for procurement at some time in the future.

APPENDIX A

MSC 06744
Draft Revision C
June 1973

DESIGN REQUIREMENTS SPECIFICATION
FOR A
VISUAL SIMULATION SYSTEM
FOR THE
SHUTTLE MISSION SIMULATOR

Prepared By:

MCDONNELL DOUGLAS ELECTRONICS COMPANY

Submitted in accordance with the Data Requirements List, line item number 3, and the Data Requirements Description, number 3, contained in Contract Number NAS 9-12651.

1.0 SCOPE

This specification contains the overall requirements for the visual simulation portion of the Space Shuttle Mission Simulator. The purpose of the specification is to define:

a. The scene elements and perceptibility required for a continuous simulation of appropriate scenes during all mission phases.

b. The fields of view and viewing geometry required to conform to the Orbiter Vehicle Window configuration.

c. The scene dynamics requirements resulting from Orbiter Vehicle maneuvering capability during ascent, on-orbit, re-entry and landing operations.

2.0 DEFINITIONS

2.1 AXIS SYSTEMS

a. Local Horizontal Reference System - A right-hand axis system whose origin is at the vehicle c.g., whose X axis is coincident with the horizontal projection of the velocity vector, and whose Y axis is in a horizontal plane.

b. Local Earth Reference System - The origin of this system lies on the surface of the Earth at the intersection of the geometric radius to the vehicle. The X_E axis is positive East, the Y_E axis is positive South and the Z_E axis is positive toward the center of the Earth.

c. Launch Earth Reference System - This system is the Local Earth system whose origin is fixed at the launch site.

d. Landing Earth Reference System - This system is the Local Earth system whose origin is fixed at the intersection of the runway threshold and runway center line.

e. Body Axis System - A conventional aircraft body axis system with X_B and Z_B in the plane of symmetry and Y_B positive out the right wing. The origin is at the center of gravity.

2.2 VISUAL DETECTION AND RECOGNITION

a. Detection: The process of determining the existence or presence of an object within the specific visual environment presented to the observer.

b. Recognition: The process of classifying the object as belonging to the set of those objects known to the observer by previous experience.

c. Identification: The process of establishing the uniqueness of the object within the set of objects known to the observer by previous experience.

2.3 ACRONYMS

AM - Applications Module
FAA - Federal Aviation Administration
ILS - Instrument Landing System
MSS - Manned Space Station
SOW - Statement of Work
KSC - Kennedy Space Center
RMS - Remote Manipulator System

3.0 SCENE ELEMENTS

The basic scene elements which comprise the visual scene shall be as specified in the following sections. In addition to the specific requirements presented below, the following general requirements shall apply to all scene elements:

(a) Depth Perception - Monocular depth perception shall be provided in all visual scenes. No portion of the displayed image shall be closer than 60 feet from the observer.

(b) Geometric Distortion - Geometric distortion in the forward and payload fields of view shall not exceed $\pm 2\%$ in adjacent $50^{\circ} \times 37.5^{\circ}$ horizontal and vertical sectors.

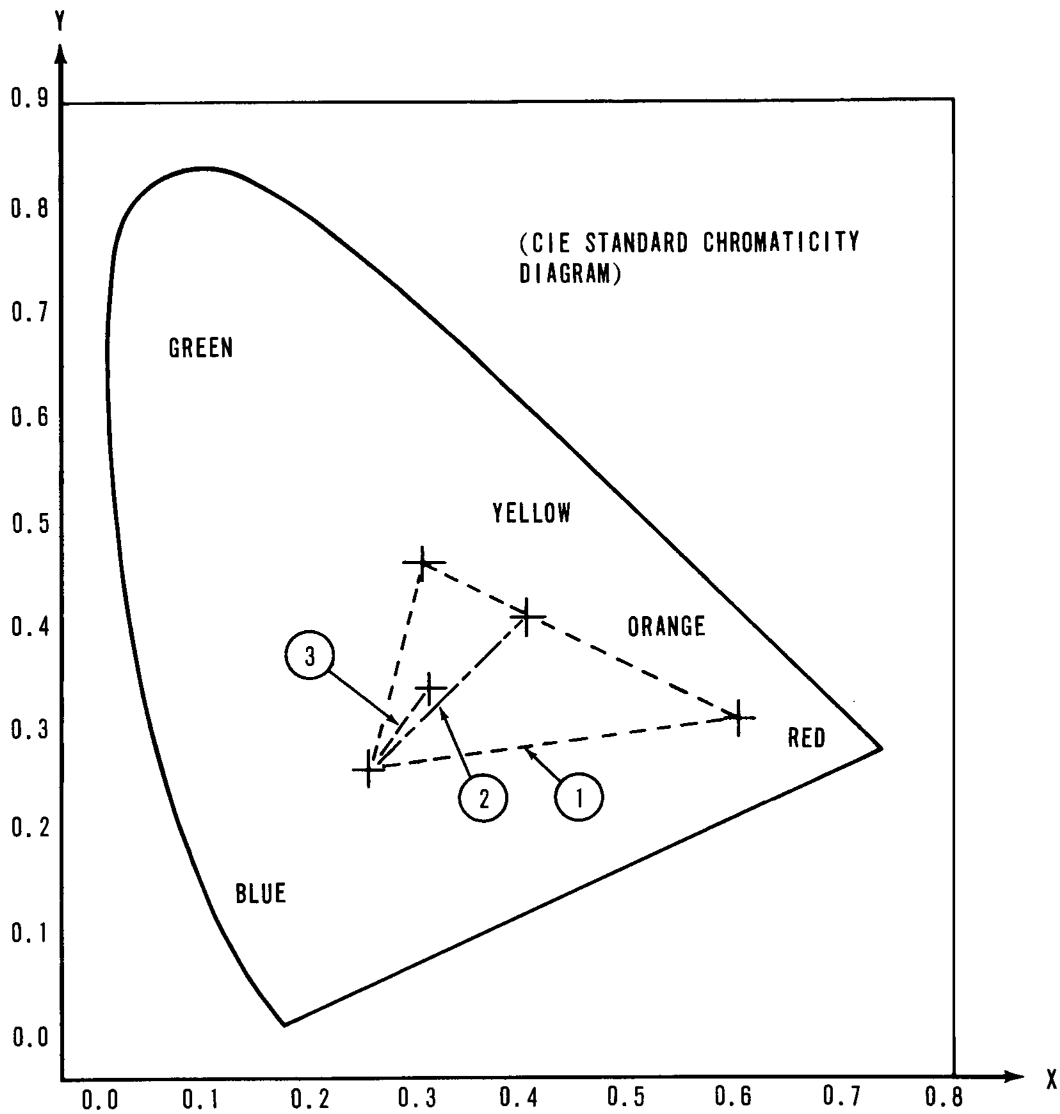
(c) Image Stability - The effect of extraneous factors (e.g. electrical noise, mechanical vibration, long-term drift) on viewed image positional stability shall be less than ± 1.0 arc minutes in any 50° horizontal $\times$ 37.5° vertical image sector.

3.1 DAYLIGHT SKY/CLOUD SCENE ELEMENT

The Daylight Sky/Cloud scene element shall consist of a cloud pattern against sky background. The scene element shall be presented in color. At least five distinguishable hues shall be provided, referenced to the Sky/Cloud scene chromaticity line shown in figure 1. The luminance of the cloud pattern shall be at least 10 foot lamberts, with 10 distinguishable luminance levels. The maximum luminance of the sky shall be one-half the maximum luminance of the clouds. It shall be possible to fade the sky/cloud luminance down to 0.01 foot lamberts.

3.2 STAR FIELD (NIGHT SKY) SCENE ELEMENT

The star field scene element shall contain at least 1,000 stars distributed against a dark background over the celestial sphere. Navigation stars shall be positioned to a relative accuracy of ± 3 arc minutes. Other stars shall be positioned to an accuracy of ± 15 arc minutes and shall permit recognition of 88 major constellations. Stars in the visible magnitude range of -1 to +5 shall



		X	Y
1	TERMINAL AREA SCENE	0.25	0.25
		0.60	0.30
		0.30	0.45
2	EARTH SCENE	0.25	0.25
		0.40	0.40
3	DAYLIGHT SKY/CLOUD SCENE	0.25	0.25
		0.31	0.33

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FIGURE 1 SCENE ELEMENT CHROMATICITY REQUIREMENTS be simulated. The stars shall be presented in white at CIE chromaticity coordinates in the vicinity of $x = 0.30/y = 0.30$. The lowest intensity stars shall be visible against a background illuminance of 0.01 foot candles. The stars shall be simulated over the required stellar magnitude range with an intensity scale of 64:1, intensity increments of 2:1 between adjacent stellar magnitudes shall be provided. Star size in the case of the brightest star (-1.0 magnitude) shall not exceed 5 arc minutes subtense to the unaided eye, positioned at the nominal eyepoint location.

3.3 EARTH SCENE ELEMENT

The Earth Scene Element shall consist of orbital earth scenes in the altitude range 3×10^6 feet to 1.5×10^5 feet, transitioning to high altitude earth scenes in the range 1.5×10^5 feet to 1.2×10^4 feet. The high altitude earth scene shall provide 1,000 nm x 1,000 nm maneuvering freedom centered at the KSC facility. Variable cloud cover, and day/night effects shall be provided. Topographical and cultural detail shall be observable in cloud-free regions, and areas of light density cloud cover. The Earth Scene Element shall be in color. A minimum of eight distinguishable hues referenced to the Earth Scene chromaticity line shown in figure 1, shall be provided. The maximum scene luminance shall be five foot lamberts with ten distinguishable luminance levels. In the case of orbital earth scenes, detectable detail shall be provided in 50 landmark areas within elementary areas subtending 6 arc minutes. In other areas, detail subtending elementary areas of 18 arc minutes shall be provided. The specified detail shall be provided at a nadir viewing distance of 3×10^5 feet. High altitude earth scene detail shall be provided with 200 foot granularity in a central area of interest of radius 25 nm located at Shuttle mission flight operations center, and 1,500 feet granularity elsewhere.

3.4 TERMINAL AREA SCENE ELEMENT

The Terminal Area Scene Element shall provide maneuvering freedom over an area of terrain 20 nm x 20 nm centered at the orbiter landing facilities at KSC. Scenes shall be provided to support energy dissipation, heading alignment, final approach, go-around and landing phase maneuver, corresponding to a simulated eyepoint altitude range of 1.2×10^5 to 25 feet. The major cultural and topological features of the KSC facilities and all outlying areas shall be provided in the Scene Element. Scene detail shall be continuously revealed as the landing area is approached, and shall be maximized in the landing area. In the immediate landing area, scene detail

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shall be provided at a level such that an object subtending 6 arc minutes at a line of sight range of 800 feet is detectable.

The immediate runway area shall contain a landing strip 10,000 feet by 150 feet equipped with IVALA (Integrated Visual Approach Landing Aid) including 3,000 feet of approach lighting, roll guidance bars, and sequenced flashing lights. A Visual Approach Slope Indicator (VASI) with slope angle of 13°, usable at 10 nm range in clear visibility shall be provided. The landing strip shall be equipped with all weather markings, touchdown zone and centerline lighting.

The Scene Element shall be usable under a range of simulated weather conditions from clear visibility through FAA Category III C conditions, both day and night.

Modifications to the KSC facilities specific to Shuttle Mission Operations of landmark proportions (maintenance facilities, service roads, control towers, radio navigation aids buildings) shall be included in the Scene Element.

The Scene Element shall be provided in color with eight distinguishable hues referenced to the terminal area scene chromaticity diagram shown in figure 1.

3.5 RENDEZVOUS/DOCKING TARGET AND PAYLOAD SCENE ELEMENT(S)

A Rendezvous/Docking Target or Payload Scene Element shall consist of one of the population of targets presented in table 1 or payloads presented in table 2. The scene element shall be in color. Eight distinguishable hues selected from the Terminal Area Scene chromaticity line shown in figure 1 shall be provided. The Scene Element luminance shall be at least 10 foot lamberts with 10 distinguishable luminance levels. At line of sight ranges of 30 feet, detectable detail shall be within visual angles of 6 arc minutes or less.

3.6 AFT ORBITER SCENE ELEMENT

The Aft Orbiter Scene Element shall contain the detail outlines, edges and surfaces of the aft orbiter body with cargo bay doors open and RMS system stowed. The Scene Element shall provide for the simulation of single arm RMS dynamics, and interactive with target, payload, and Rendezvous objects. Detectable detail

TABLE 1

RENDEZVOUS & DOCKING TARGETS

Device	Principal Characteristics & Dimensions
MSS Core Module	Cylindrical with truncated conical docking ports. Overall length 41'6", overall diameter, 12'. Multiple passive docking ports distributed over outer surface.
Partially Assembled MSS	Core module with one or more applications modules attached. Applications module to be selected from a family of 7 cylindrical devices, diameters 14 feet, overall lengths varying from 18.3 to 68.5 feet. External subsystems include solar cell arrays, docking drogues and probes; deployable EVA inspection hatches.
Orbiter Vehicle	Characteristics as for baseline orbiter vehicle.
Detached Applications Modules	Family of 7 cylindrical devices, diameter 14 feet, lengths varying from 30 to 33 feet. Externally visible components as for attached AM's.

TABLE 2

PAYLOAD TYPES

Device	Principal Characteristics & Dimensions
Habitable Module	Cylindrical, 15' diameter by 14'9" length, equipped with viewports, access tunnel and hatch.
Orbit-to-Orbit Shuttle (OSS)	Cylindrical with engine nozzle. Overall length 35.2 feet, diameter 15 feet.
Intelsat IV	Cylindrical, 103 inches diameter, 111 inches length, with attached spheres.
DI-T Centaur Modified for Shuttle Operations	Cylindrical, overall length 32', diameter 10'. Engine nozzle visible in end-on axial view.
Agena Propulsion Stage	Cylindrical, overall length 20', diameter 5'. Engine and engine nozzle clearly visible aft.
TIROS Surveillance Satellite	Complex cube approximately 40" side, 3 deployable solar panels. Externally visible subsystems include S band antenna, scanning radiometer, momentum flywheel and TV camera optics.

shall be presented subtending angles of 6 arc minutes at viewing distances greater than 20 feet. The aft structure shall be in color. The range of available hues shall be that specified for the Rendezvous/Docking Target and Payload Scene Elements on the CIE standard chromaticity chart. Scene Element luminance shall be at least 10 foot lamberts with 10 distinguishable luminance levels.

4.0 ORBITER VIEWING GEOMETRY REQUIREMENTS

4.1 VEHICLE COMMAND PILOT STATION

The Command Pilot nominal eyepoint shall be situated 18" to the left of the plane of vehicle symmetry, with 27" eye relief along the forward line of sight, and 18" eye relief to the left window in a direction 90° left of the forward line of sight. The forward horizontal and vertical front window visibility is as shown in figure 2. The total forward field of view is defined to include forward, front and side window visibility. A spherical viewing volume of six inches radius shall be provided centered at the Command Pilot eyepoint.

4.2 VEHICLE PILOT STATION

The Pilot nominal eyepoint shall be situated 18" to the right of the plane of vehicle symmetry. The front window visibility is as shown in figure 2, but laterally inverted about the zero degree vision envelope ordinate. A viewing volume of six inches radius shall be provided, centered at the Pilot eyepoint.

4.3 PAYLOAD HANDLING STATION

The Payload Handling Station viewing geometry, eyepoint locations and eye relief shall be as shown in figure 3. Eyepoint locations shown are those corresponding to overhead (location A), Aft (location B) and furthest Aft (location C), during overhead and aft RMS operations. A spherical viewing volume of six inches radius, permitting viewing at locations A and B shall be provided as a minimum.

5.0 VISUAL SCENE CONTENT AND DYNAMICS REQUIREMENTS

The visual simulation system scene content and visual perceptibility for the ascent, on-orbit and descent mission phases, and for the ferry mission shall be as specified in the following paragraphs. Scene element dynamics are specified for all mission phases in table 3.

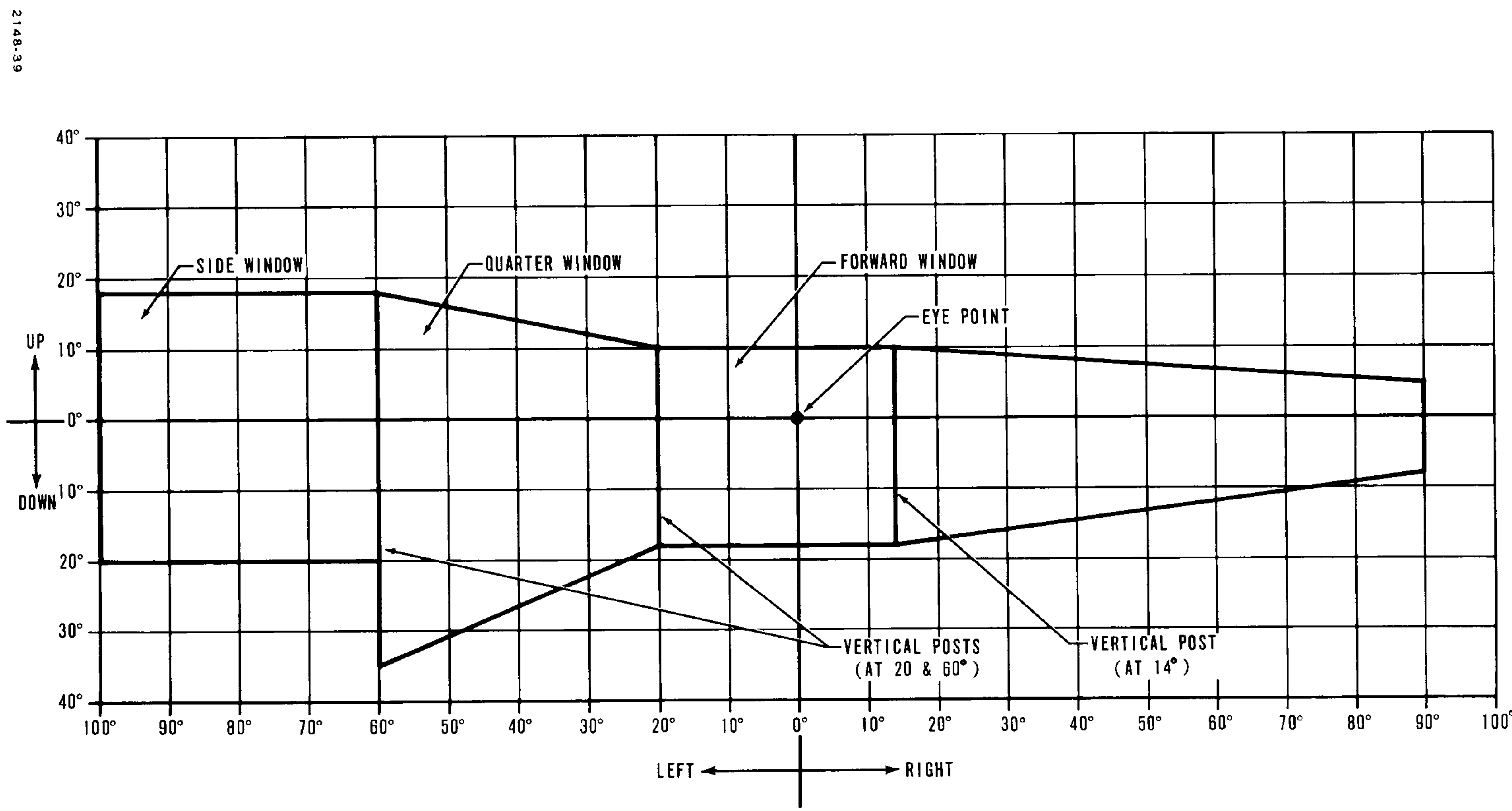

FIGURE 2 FORWARD FIELD OF VIEW REQUIREMENTS

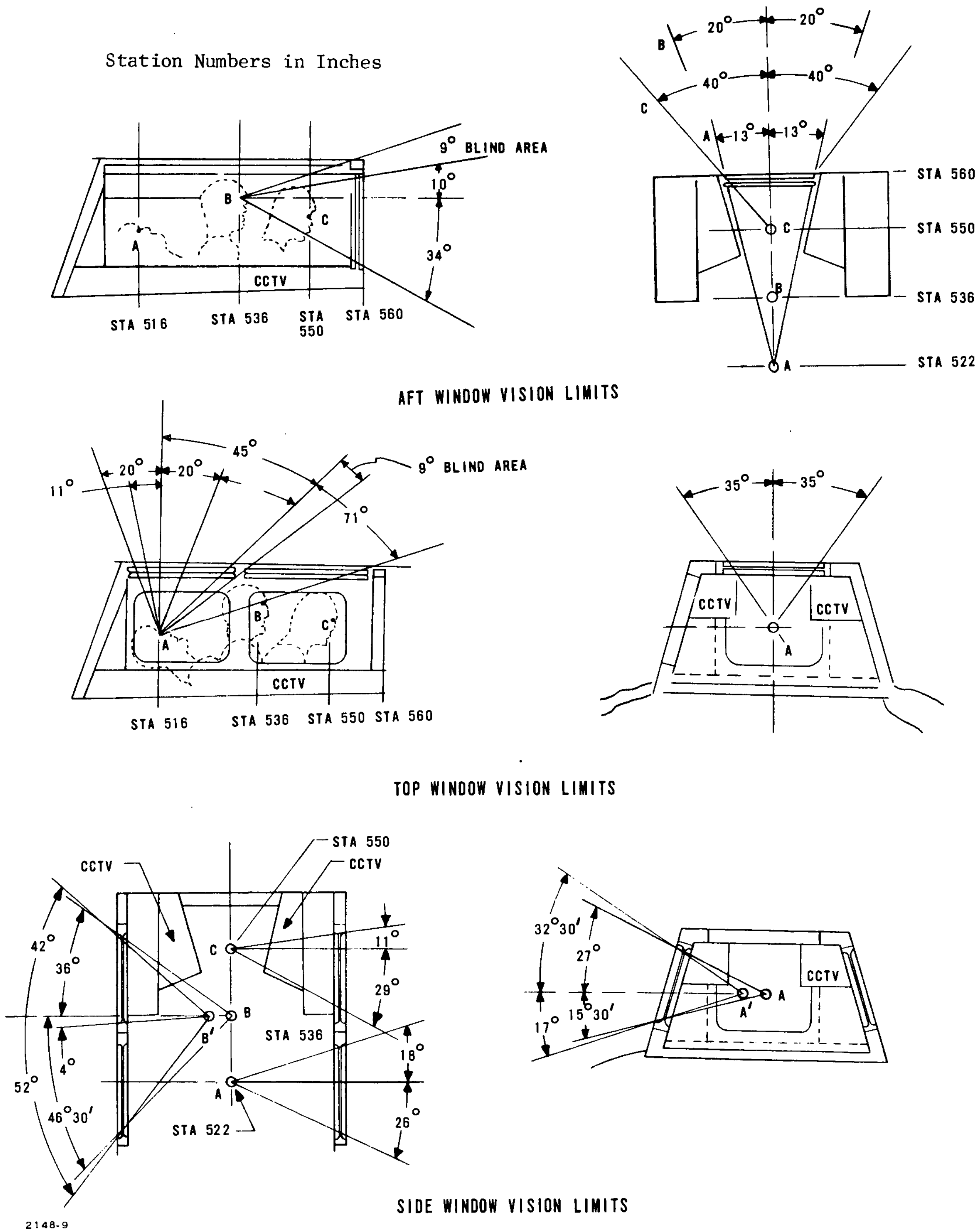

FIGURE 3 PAYLOAD HANDLING STATION VISIBILITY

TABLE 3
SCENE ELEMENTS DYNAMICS REQUIREMENTS

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PARAMETER / SCENE	ANGULAR EXCURSION			ANGULAR RATES			ANGULAR ACCELERATION			TRANSLATIONAL EXCURSION			TRANSLATIONAL RATE			TRANSLATIONAL ACCELERATION			REMARKS
	ϕ	θ	ψ	$\|\dot{\phi}\|$	$\|\dot{\theta}\|$	$\|\dot{\psi}\|$	$\|\ddot{\phi}\|$	$\|\ddot{\theta}\|$	$\|\ddot{\psi}\|$	X_E	Y_E	Z_E	$\|\dot{X}_E\|$	$\|\dot{Y}_E\|$	$\|\dot{Z}_E\|$	$\|\ddot{X}_E\|$	$\|\ddot{Y}_E\|$	$\|\ddot{Z}_E\|$	
ASCENT PHASE CLOUD/SKY EARTH AND STAR FIELD	-5 TO +5 DEG	-5 TO +95 DEG	-35 TO +95 DEG	0 TO 0.4 r/SEC	0 TO 0.2 r/SEC	0 TO 0.3 r/SEC	0 TO 0.9 r/SEC^2	0 TO 0.8 r/SEC^2	0 TO 0.75 r/SEC^2	N.A.	N.A.	100 TO 3.1×10^5 FT	0 TO 3×10^4 FT/SEC	0 TO 3×10^4 FT/SEC	0 TO 3×10^3 FT/SEC	0 TO 150 FT/SET^2	0 TO 150 FT/SEC^2	0 TO 100 FT/SEC^2	LAUNCH EARTH RELATIVE $0 \le X_{LE} \le$ TBD $0 \le Y_{LE} \le$ TBD $100 \le Z_{LE} \le 3.1\times10^5$ FT
ASCENT ABORT PHASE CLOUD/SKY EARTH AND STAR FIELD	CASE (1) LAUNCH COMMIT TO 30 SECONDS: SCENE DYNAMICS SAME AS ASCENT PHASE CASE (2) LIFT OFF PLUS 30 TO 86 SECONDS: SCENE DYNAMICS SAME AS ASCENT AND DESCENT PHASE CASE (3) ONCE AROUND: SCENE DYNAMICS SAME AS FOR ALL MISSION PHASES																		
ON-ORBIT PHASE EARTH/CLOUD SCENE AND STAR FIELD	CONTINUOUS			0.0025 TO 12 DEG/SEC	0.01 TO 1.5 DEG/SEC	0.01 TO 10.5 DEG/SEC	10^{-4} TO 8.25 DEG/SEC^2	10^{-4} TO 4.6 DEG/SEC^2	2.5×10^{-5} TO 5.35 DEG/SEC^2	*	*	3×10^5 TO 36×10^5 FT	0 TO 3×10^4 FT/SEC	0 TO 3×10^4 FT/SEC	0 TO 103 FT/SEC	0 TO 7.5 FT/SEC^2	0 TO 7.5 FT/SEC^2	0 TO 7.5 FT/SEC^2	*ORBITAL INCLINATION RANGE EASTERLY: +65 TO -125 DEG POLAR: 165 TO 145 DEG ORBITAL RATE, STAR FIELD REL $1.2\times10^{-3} \le \omega \le 1.3\times10^{-3}$ RAD/SEC
TARGET SCENE ELEMENTS	-5 TO +5 DEG	-5 TO +5 DEG	-5 TO +5 DEG	0 TO 1 DEG/SEC	0 TO 1 DEG/SEC	0 TO 1 DEG/SEC				RANGE $50 \le R \le 3\times10^5$ FEET			VELOCITY $0 \le V \le 100$ FT/SEC			ACCELERATION $0 \le A \le 10$ FT/SEC^2			ANGULAR-TARGET REF RELATIVE TRANSLATIONAL-LINE OF SIGHT REL
MANIPULATOR ARMS	SEE TABLE 4																		
CARGO BAY DOORS	NOT REQUIRED (DOORS ARE OPENED AND CLOSED WHEN PAYLOAD HANDLER STATION NOT MANNED)																		
DESCENT PHASE DE-ORBIT AND EXOATMOSPHERE	EARTH/CLOUD SCENE AND STAR FIELD SAME AS ON-ORBIT PHASE																		
HYPERSONIC ENTRY AND TRANSITION	-100 TO +100 DEG	-20 TO +70 DEG	-180 TO +180 DEG	0 TO 0.5 r/SEC	0 TO 0.2 r/SEC	0 TO 0.5 r/SEC	0 TO 0.01 r/SEC^2	0 TO 0.01 r/SEC^2	0 TO 0.025 r/SEC^2	N.A.	N.A.	8×10^4 TO 3×10^5 FT	5000 TO 3×10^4 FT/SEC	5000 TO 3×10^4 FT/SEC	50 TO 1000 FT/SEC	0 TO 30 FT/SEC^2	0 TO 30 FT/SEC^2	0 TO 30 FT/SEC^2	TRANSLATION, LANDING EARTH REL 100 NM $\le X_{LE} \le$ 5000 NM 50 NM $\le Y_{LE} \le$ 1200 NM $8\times10^4 \le Z_{LE} \le 3\times10^5$ FT
MAX L/D CRUISE AND ENERGY DISSIPATION	-60 TO +60 DEG	-20 TO +20 DEG	-180 TO +180 DEG	0 TO 30 DEG/SEC	0 TO 10 DEG/SEC	0 TO 10 DEG/SEC	0 TO 85 DEG/SEC^2	0 TO 30 DEG/SEC^2	0 TO 40 DEG/SEC^2	-30 TO 100 NM	-50 TO 50 NM	3×10^4 TO 1.2×10^5 FT	0 TO 3000 FT/SEC	0 TO 3000 FT/SEC	50 TO 300 FT/SEC	0 TO 60 FT/SEC^2	0 TO 60 FT/SEC^2	2 TO 20 FT/SEC^2	TRANSLATIONAL VALUES ARE LANDING EARTH RELATIVE
APPROACH AND LANDING	-60 TO +60 DEG	-20 TO +40 DEG	SAME AS MAX L/D CRUISE							0 TO 15 NM	0 TO 15 NM	0 TO 3×10^4 FT	0 TO 500 FT/SEC	0 TO 500 FT/SEC	0 TO 200 FT/SEC	0 TO 30 FT/SEC^2	0 TO 30 FT/SEC^2	0 TO 60 FT/SEC^2	
FERRY OPERATIONS	SCENE DYNAMICS SAME AS DESCENT PHASE APPROACH AND LANDING																		

5.1 ASCENT PHASE

5.1.1 Scene Content

The ascent phase visual scene shall consist of the Daylight Sky/Cloud, Star Field, and Earth Scene Elements. The visual scene shall fill the command pilot and pilot forward fields-of-view. A visual scene at the Payload Handler station shall not be required.

The scene shall initially consist of the Daylight Sky/Cloud and Earth Scene Elements. At the appropriate point along the ascent pro-field (approximately 80,000 feet), the Sky Scene Element shall fade to near darkness and the Star Field shall appear such that maximum Star Field brightness is reached at approximately 180,000 feet altitude. Horizontal definition shall be provided by luminous gradation within a visual angle of approximately three degrees, fading smoothly from Earth Scene Element luminance to Daylight Sky or Star Field background luminance.

5.1.2 Motion Cue Coordination

During ascent the dynamics of the visual scene shall be coordinated with, as a minimum, the following motion cues:

a. Launch attitude simulation
b. Lift-off transients
c. POGO longitudinal vibration: 0 - 1.4 Hz
d. Ascent steering transients, lateral and longitudinal
e. Aerodynamic transients
f. SRM separation tip-off
g. Engine shutdown transients

5.2 ASCENT ABORT PHASE

Scene content corresponding to two principal Ascent abort cases shall be provided in the forward field:

a. Abort from a vehicle altitude of between 12,000 feet and 2,000 feet.
b. Abort from a vehicle altitude of between 80,000 feet and 12,000 feet.

In case a. the scene content shall consist of the Terminal Area Scene Element at that time at which the vehicle attitude permits forward field viewing. In case b. the Earth Scene and Terminal Area Elements shall be provided in a smoothly transitioning sequence.

5.3 ON-ORBIT PHASE

5.3.1 Scene Content

The on-orbit phase scene shall consist of the Star Field and Earth Scene Elements and those scene elements specified below, during specific sub-phases. The Earth and Star Field Scene Elements shall fill the command pilot and pilot forward fields-of-view, as a function of vehicle attitude, during all on-orbit sub-phases except as occulted by other scene elements as specified below. The horizon (Earth/Star Field interface) shall be as defined in 5.1.1.

5.3.1.1 Rendezvous

A Rendezvous Target Scene Element shall appear within the visual scene in the command pilot and pilot forward fields-of-view at expected maximum visual range. The effects of target glint and identification beacons which enhance target detection range shall be simulated. The target shall grow in size to a recognizable object, with illumination corresponding to the appropriate sun angle during rendezvous braking maneuvers. At the completion of the rendezvous maneuver, the target shall appear at a station keeping range of 50 feet minimum. At this distance, the target shall show detail corresponding to major external physical characteristics. The outline of the rendezvous target shall appropriately occult the Earth Scene and Star Field.

5.3.1.2 Docking and Undocking

5.3.1.2.1 Command Pilot and Pilot Field-of-View

The final closing maneuvers prior to aft docking shall translate the Docking Target Scene Element from the forward field to the payload handling field of view. Undocking, separation, and station-keeping maneuvers shall restore the target to the forward field to a station-keeping location.

5.3.1.2.2 Payload Handling Station

During aft docking and undocking operations, the field of view applicable to the Payload Handling Station shall be filled with Star Field and Earth Scene Elements, depending upon the orientation of the orbiter vehicle. In addition, the Aft Orbiter Scene Element shall be displayed with a view of the cargo bay doors, exposed cargo bay area, and deployed docking adapter. The Docking Target Scene Element shall appear in the Payload Handling Station field of view during closing maneuvers. Orbiter docking maneuvers relative to the rendezvous target shall be accomplished using visual cues provided by the target. In the case of close-in maneuvers, the out-the-window scene shall be fully coordinated with the RMS wrist mechanism television display. For docking and undocking operations requiring the use of the RMS system, the deployment, engagement and operation of the wrist mechanism with the rendezvous target docking mechanism shall be displayed in the out-the-window scene. The target, orbiter docking adapter and/or RMS system shall be displayed with a level of scene detail to enable correction of initial angular alignment errors down to $\pm 0.3^{\circ}$, and positional errors of ± 6 inches.

5.3.1.3 Payload Deployment and Separation

5.3.1.3.1 Payload Handling Station

The Payload Handling Station field-of-view shall contain the Aft Orbiter, Payload, Earth and Star Field Scene Elements. The payload deployment sequence of RMS operation and Payload Scene Element release shall be provided in the visual scene, and be coordinated with the RMS wrist mechanism television system display at the handling station. Changes in orbiter attitude during payload deployment and separation due to orbital motion shall be evident by appropriate changes in relative position between the observable detail of the Aft Orbiter Scene Element and the Payload and/or Earth Scene Elements.

5.3.1.3.2 Command Pilot and Pilot Field-of-View

After payload deployment, and prior to payload activation or disposition, the Payload Scene Element shall be observable in the forward field of view during station keeping or visual inspection procedures. The Payload Scene Element shall appear after appropriate orbiter maneuvering to a station keeping position, at a line-of-sight range of 50 feet minimum.

5.3.1.4 Payload Recovery and Storage

5.3.1.4.1 Command Pilot and Pilot Field-of-View

The forward field-of-view shall contain the Payload Scene Element as a function of vehicle attitude and target relative position. In the case of payload capture by the deployment of telefactor arms forward of the cargo bay, the payload shall be visible in the forward field-of-view after closure to ranges corresponding to maximum reach distance of the deployed manipulator mechanism.

5.3.1.4.2 Payload Handling Station

The scene at the payload handling station during recovery and storage shall be as specified in paragraph 5.3.1.3.1. The event sequence of extension of RMS arm, payload capture and storage shall be visible from the payload station in the case of aft maneuvering and closure. The RMS system dynamics requirement during all deployment and operational maneuvering shall be as shown in table 4.

5.3.3 Motion Cue Coordination

During on-orbit operations the scene dynamics shall be coordinated with, as a minimum, the following motion cues:

a. Thruster firing impulse cues
b. Hard and soft dock impact cues
c. Manipulator/payload impact cues

5.4 DESCENT PHASE

5.4.1 Scene Content

The visual scene during the De-Orbit, Exo-atmospheric Entry and Hypersonic Entry sub-phases shall initially consist of the Earth and Star Field Scene Elements with the horizon as defined in 5.1.1. At the appropriate point along the trajectory (approximately 180,000 feet) the Star Field Element shall fade from the field-of-view and the Daylight Sky Scene Element shall fade in during those missions calling for daylight approach and landing. The fade-in/fade-out process

TABLE 4
RMS MANIPULATOR ARM DYNAMICS

2148-40

ITEM / PARAMETER	SHOULDER PITCH	SHOULDER YAW	ELBOW ROLL	ELBOW YAW	WRIST ROLL	WRIST PITCH	WRIST YAW	TIP TRANSLATION
ANGULAR RANGE	±200°	±130°	±200°	±155°	±200°	±120°	±120°	
NO LOAD RATE/VELOCITY	0.03 R/S	0.03 R/S	0.057 R/S	0.057 R/S	0.175 R/S	0.175 R/S	0.175 R/S	1.5 FT/S
NO LOAD ACCELERATION	0.015 R/S^2	0.015 R/S^2	0.028 R/S^2	0.028 R/S^2	0.087 R/S^2	0.087 R/s^2	0.087 R/S^2	0.75 FT/S^2
FULL LOAD RATE/VELOCITY	3.5×10^{-3} R/S	3.5×10^{-3} R/S	6.6×10^{-3} R/S	6.6×10^{-3} R/S	2.65×10^{-2} R/S	2.65×10^{-2} R/S	2.65×10^{-2} R/S	0.174 FT/S
FULL LOAD ACCELERATION	8.87×10^{-4} R/S^2	8.87×10^{-4} R/S^2	1.75×10^{-3} R/S^2	1.75×10^{-3} R/S^2	2.32×10^{-3} R/S^2	2.32×10^{-3} R/S^2	2.23×10^{-3} R/S^2	.0018 FT/S^2

shall be completed during the Transition and Maximum L/D Cruise sub-phase at an altitude of approximately 80,000 feet. Transition from the Earth Scene Element to the Approach and Landing Scene Element shall occur at altitudes below 12,000 feet at the boundaries of the Approach and Landing Element (20 nm x 20 nm).

5.4.3 Motion Cue Coordination

During descent, the visual scene dynamics shall be coordinated with, as a minimum, the following motion cues:

a. Impulse cues resulting from OMS retro-thruster operation.

b. Translational and rotational acceleration onset cues resulting from ACPS and aerodynamic flight control system operation.

c. Translational onset cues resulting from operation of ABES engines.

d. Cues resulting from landing gear operations including touchdown and runway rollout.

e. Random cues resulting from rough air, gusts, buffet, etc.

5.5 FERRY OPERATIONS

5.5.1 Visual Scene Content

The following requirements apply to the orbiter multi-stop Ferry operations phase. A visual scene is required for command pilot/pilot fields-of-view only.

5.5.1.1 Taxi and Take-Off

A visual scene shall be provided consisting of the Approach and Landing Airport Scene Element with taxiways to a main, all-weather, runway 10,000 feet in length by 150 feet width. Scene detail shall be provided to the level required for taxi and take-off positioning solely by the use of visual cues provided in the taxiway, runway, and airport environment scene.

5.5.1.2 Ferry Cruise and Initial Approach

In level flight, a horizon reference over cloud cover shall be provided for a range of cruise altitudes between 7,000 and 26,000 feet. Cruise range between 250 and 600 nm over cloud cover is required. The visual display shall be capable of providing a scene consistent with an initial approach 30° bank maneuver in cloud or over cloud terrain, resulting in alignment with the destination runway at an altitude of 10,000 feet, at a distance of 50,000 feet from touchdown.

5.5.1.3 Final Approach and Touchdown

The visual scene during approach and touchdown shall consist of the Approach and Landing scene element.

5.5.2 Motion Cue Coordination

During ferry mission operations, the visual scene dynamics shall be coordinated with, as a minimum, the following motion cues:

a. Acceleration onset cues resulting from flight control system, ABES, speed brake and landing gear operations including runway roll.

b. Random cues due to rough air, gusts, buffet, etc.